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On-line Water Quality Monitoring System in Borensberg, Motala, Sweden

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Abstract

In one year water research project in Borensberg Waterworks, Motala, Sweden, water quality with respect to microscopic particle accounts both in raw water and drinking water were monitored by Predect's Online Water Quality Monitoring System. Microscopic particle counts were documented with normalized value in real-time by P-100 for raw water and P-300 for pure water. This report aimed to evaluate the system for microbial contaminants condition in water.

Statistical tools were used for data sorting and arrangement. Pearson correlation matrix and regression analyses were applied for correlation analysis on variables of total particle counts in raw water and drinking water as well as within all particle size fractions. Furthermore, the similarities and difference of microbial particle counts between the two water bodies and seasonal variations were also discussed and analyzed. Log Reduction was used to measure particle removal for comparison of different treatment processes. Numerical analysis of GEV followed by recurrence curve analysis was suggested for threshold value definition.

Results show that Predect's design could be used as an early warning system against contaminants in terms of microscopic particle counts and inform the operator through GMS system and at the same time immediate auto-sample is processed. Correlation analysis show that there is no linear relation exists between total particle counts in raw water and drinking water. While in specific time periods, there exists variable correlation between all particle size fractions both within and between raw water and drinking water. Apparently, there are good correlation between almost all size fractions in Dec.2009, Mar.2010 and Jun.2010. It also demonstrates that there is a weak positive relation between microscopic particles in drinking water and microbiological counts in raw water.

Results from Log Reduction analysis show that the average values of Log Reduction is 2.82 in summer time and 1.05 for annual average situation. Comparison analysis between Borensberg Waterworks and Arboga Waterworks shows that this system can be used to demonstrate different treatment processes. Results from threshold value definition show that the starting value should be determined by combination of theoretical analysis and practical situation.

Key Words: Online Water Quality Monitoring System, microbiological water quality, microbiological contaminants, Borensberg Waterworks, Log Reduction, GEV (Generalized Extreme Value), threshold definition.

Contents

Preface and Acknowledgements

This master thesis was performed during the winter of 2010 at Lund University of Water Resources Engineering Department being involved in a water research project granted by Swedish Water Development in Sep. 2009 and cooperated together with Predect AB and SWECO AB.

First of all, I would like to give my sincere gratitude to kind Professor Kenneth M. Persson for giving me this opportunity to get a head start of my consultant career. Many thanks are given as well to Scientist Sudhir Chowdhury and Manager Ulla Chowdhury for their technical support, data provision and valuable guidance through the whole study period.

I am grateful for the teaching group for International Program of Water Resources for its high advanced education and professional guidance and careful thoughts! Your commitment and ambitions towards academic research and study and teaching are highly appreciated.

Many thanks to a number of friends who have been accompanying and encouraging me through my life in Lund: Jonas Althage, Caroline Fredriksson, Elvis Asong Zilefac, Aude Baillon-Dhumez, Denzil Weerakkody, Abbas Hosseini, Gustaf Lustig, Benedict Rumpf, Aamir Ilyas, Lena Flyborg, Hanna Modin, Godlisten Mroso, Magdalena Wolynczyk,Ying Xiao, Lin Wang, Zhenlin Yang, You Lv, Jinghua Chen, Feifei Yuan, Shuang Liu.

This master thesis is especially given as a gift to my dear family and especially to my grandma, for their powerful and valuable spiritual support. It deserves to use all my life to reward their giving and unconditional love!

Glossary

Cryptosporidium: a parasitic protozoan that belongs to the phylum protozoa.

CE: CE stands for Conformité Européenne (''in conformity with EC Directives''). CE marking is a product which is labeled with the European Community.

Feret's diameter: Feret's diameter is used to get an average value of particle size by using microscopic measurements.

GLAAS: UN-Water Global Annual Assessment of Sanitation and Drinking-Water

GMP (Good Manufacturing Practice): This is part of a quality system covering the manufacture and testing of active pharmaceutical ingredients, diagnostics, foods, and pharmaceutical products medical devices. GMPs are guidelines that outline the aspects of production and testing that can impact the quality of a product.

GEV: Generalized Extreme Value

ISO 14644 Standards: were first formed from the US Federal Standard 209E Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones.

In situ: In biology, in situ means to examine the phenomenon exactly in place where it occurs (i.e. without moving it to some special medium).

ISO 14698: It features two international matches on Bio-contamination normal controls.

JIS B 9925-1997: Light scattering automatic particle counter for liquid JIS B9925

LASER: Acronym for Light Amplification by Simulated Emission of Radiation, which is a high-intensity coherent light.

Normalized Counts: It is the total number of particles divided by the sampled volume.

Pure Water: Pure water is also known as purified water that is water from a source that has removed all impurities.

PSD: Particle Size Distribution

Raw water: The water which is taken from the environment, and is subsequently treated or purified to produce potable water in a waterworks.

USP 797: It is a far-reaching regulation that governs a wide range of pharmacy policies and procedures.

1 Introduction

Clean drinking water which is most essential and valuable resource for humanity is becoming the most threatening resource to the health of human beings nowadays. It was estimated by WHO that in a global scale, there are about 900 million people lacking access to clean water resources and nearly 2/15 of the world's population(2.6 billion people) lacking access to improved sanitation services (WHO, 2010). Furthermore, there is evidence that diseases related to water, sanitation and hygiene account for around 2,213,000 deaths per year according to Disability Adjusted Life Years (DALYs) (Prüss et al, 2002).

As water is not only for life-sustaining to humans but also for the survival of all organisms, water-borne diseases caused by drinking water contaminated by human or animal faeces containing pathogenic microorganisms are transmitted directly when the water is consumed. Those microbial bacteria such as Cryptosporidium, Giardia and E-coli bacteria are the sources of frightening diseases such as Anemia, Cholera, Giardiasis and Diarrhoea, etc. (WHO, 2010).

Awareness about the drinking water quality and the protection of water supply system is becoming sensory and visible to the public. It is not only for the water scarcity problem but also for the freshwater quality. There have been more and new infections from those water-borne diseases. Furthermore, more socioeconomic influence of these illnesses would be caused due to factors such as global warming, chronic water shortage and population growth etc. (Schnabel, 2009).

The most recent outbreak happened in the end of Nov. 2010, Östersund Municipality, in north Sweden, during which over 2500 people were sick from the outbreak of Cryptosporidium. The disaster is a good reminder for both individuals and government that the technology which can help to provide a warning system and stop the outbreak in the source should be applied more extensively all over the country (Östersund Municipality, 2010) It evokes a series of discussion about how to build up an effective water quality protection system and make security of public water supply.

As early as 1875, Sweden set up legislation of communicable disease for selecting the disease agents, occurrence and the severity of the disease. Country Medical Officers are responsible for handling with such diseases and overseeing and coordinating to fight against communicable diseases in their region (Andersson & Bohan, 2001).

The core mission of technicians and experts in water sector is to provide sustainable and effective technical solutions to treat and distribute various water flows in order to minimize water born pollutants and reduce risks to public health and to offer domestic, industrial and agricultural consumers with safe drinking water and process water.

Currently, the water quality analyses with respect to microbial contaminants in municipal water facilities don't provide results in real time when water becomes polluted. This results delayed valuable time to take corrective measures to cope with the problems detected.

The link between the scaring communicable disease and the spread of waterborne infection is usually not clear. By combination with an online in real time instrument to detect the microbiological particles makes it possible to generate a clear link between them (Persson, 2010).

Recently, online water quality monitoring systems based on sensor technologies are fast developed, allowing water utility managers to continuously monitor the quality in terms of physical and chemical indicators through the drinking water distribution systems possibly in real time.

The initial of this thesis is based on interests of this new and advanced technology in water resources management. The opportunity to be involved in Swedish National Water Research in Motala, joining evaluation of an Online Water Quality Monitoring System designed by a Swedish company named Predect AB is highly appreciated.

This paper aims to evaluate Predect's advanced technology through statistical analysis of particle distribution, seasonality analysis, and correlation and regression analysis. Comments on identification of water quality parameters, establishment of threshold values by using Numerical Method (GEV) and detection of different water treatment processes and equipment improvement were also discussed.

1.1Background

WHO has identified water contamination as the most serious health risk and Cryptosporidium is regarded as the clearest example of new threats (WHO, 2010). Waterborne diseases which are caused by the parasites Cryptosporidium and Giardia are priorities according to the Swedish Water and Food Administration (SWFD, 2010).

EU Water Directive stresses that all members should take all necessary measures to make sure that the regular monitoring of the quality of water used for human consumption is applied and samples collected should be representative of the quality of the water consumed through the year. It also addresses that any contaminants and by-products caused by disinfection should be monitored as well (Eddo, 2008).

Specified requirements for alerting or devices that warn when errors occur in the water are commented by SWFD (Vägledning, Swedish Food Authority, 2001). Although there are no specific rules to guide how to executive the warning functions, there are clear guidelines and requirements about the alarming system on what should be monitored. It defines the alarming system as the one which detects and records the data at the point (time and space) in which errors can arise or trigger a warning in the form of a clearly audible and/or visual signal when a numeric measurement value (alarm limit) reaches.

Normally the pH adjustment, disinfection and monitoring of turbidity are those where errors can occur at any time. In such cases, detection, alert and warning should take

place continuously and automatically (SLVFS, 2001:30).
The alarm and control equipment should be independent and alarm features should be checked regularly. When a water utility is under unattended equipment, it should be linked to a manual operation center or similar to keep a continuous monitoring process. For very small water utilities, there should be enough to trigger an audible warning to the attention of local residents (SLVFS, 2001:30).
Hence the following situation should be considered with respect to an online monitoring system.

1) Chloride meter should be installed as a disinfection monitoring advice for waterworks where chlorination is used for disinfection.

2) Turbidity meter is used after filter installation.

3) Monitoring operation should be done when there is adjustment of pH.

More details are referred to the official journal about water quality monitoring in Vägledning till Livsmedelsverkets föreskrifter (SLVFS, 2001:30) om ricksvatten(Guidance to the National Food for Drinking Water).

1.2 Project Description

1.2.1 Boren Lake and Borensberg Waterworks

Boren Lake situates in Östergötaland (Fig.1), east of Motala with 73 m above sea level. It provides raw water resource for Borensberg Waterworks covering an area of 28 km^2 with a maximum depth 14 m. It forms a part of the Göta Canal and has given the city name as Borensberg which means "the shining" (Motala Municipality, 2010).

Borensberg Waterworks is located near the outlet of Boren Lake with a designed capacity of 10,000m^3/day. About 770 m^3 of water every day from Borensberg Waterworks is distributed to Borensberg and Brånshult, serving about 3000 people (2004). The Waterworks applies traditional water treatment process such as flocculation, sand filtration, disinfection by UV and with a storage tank of 300 m^3 before the distribution system.

The water in Boren Lake is quite low in nutrients. There is a wastewater treatment plant in Motala, located in upstream. Although it has introduced chemical treatment and water quality in the lake has been improved since 1975, as used as resource for municipal water supply, it is still influenced by the quality of discharge from upstream (Motala Municipality, 2010)

Boren Lake is part of the Swedish National Monitoring Program of Inland Surface Water. The program was revised at the beginning of 2007 to meet the requirements specified by the European Commission's Water Framework Directive. Parameters such as temperature, pH, TOC and other chemical elements are monitored regularly throughout the year (Motala Municipality, 2010). It is a temperate lake with temperature varying from near 0 ^{o}C to 21^{o}C. It means that seasonal circulation and mixing will influence the water quality in the raw water. A general monitoring result of water quality condition in Boren Lake in 2009 is shown in Table 1.

Besides, regular water quality test is done once per month in Borensberg Waterworks. Results done in Feb.2010 are shown in Table 2 and Table 3 for raw water and pure water respectively.

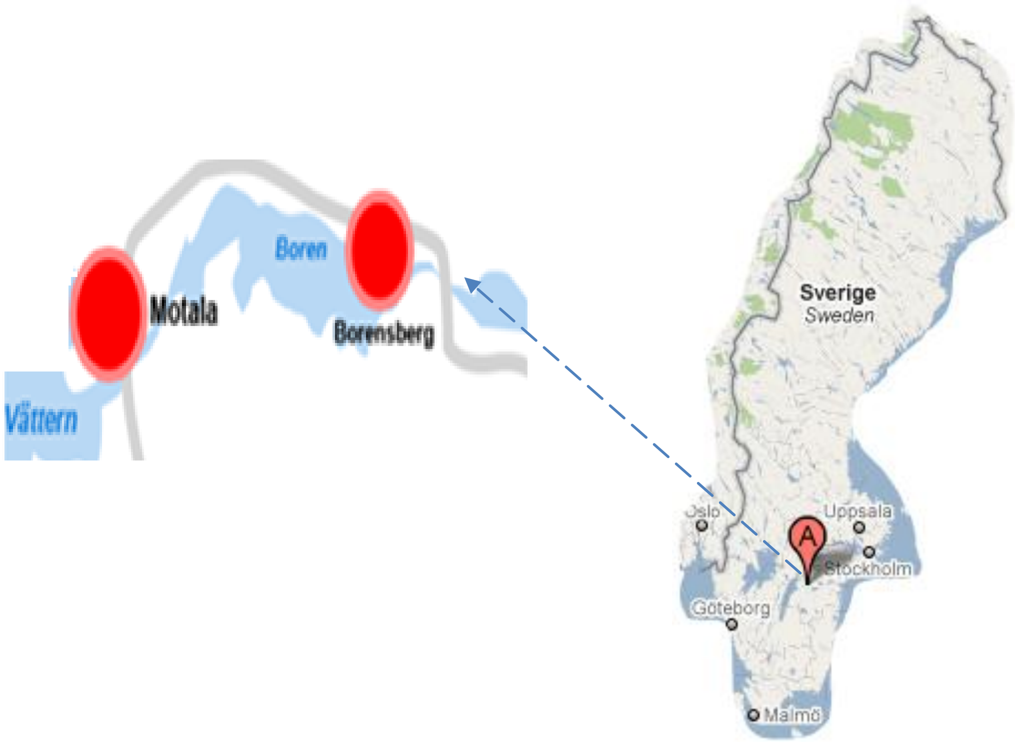


Figure.1 Location of research site, Borensberg, Motala, Sweden 2011 (Google Map)

Table 1. Boren Lake 2009.(http://www.motalastrom.org/)

Mo04 Boren utl

Datum	Temp (°C)	Syreh (mg/l)	Syrem (%)	pH	Kond (mS/m)	Alk (mekv/l)	NH4-N (µg/l)	NO2+3-N (µg/l)	Tot-N (µg/l)	PO4-P (µg/l)	Tot-P (µg/l)	Abs. 420 Filt	Turb (FNU)	TOC (mg/l)
2009-01-21	0.8	13.2	94	7.8	16	0.62	52	610	810	-	<5	0.009	0.50	2.9
2009-02-20	1.4	12.1	86	7.8	14	0.60	75	770	700	-	<5	0.010	0.24	2.9
2009-03-17	2.3	13.9	101	7.9	16	0.53	24	530	800	-	<5	0.010	0.61	3.0
2009-04-16	5.8	12.8	102	7.8	15	0.60	22	520	650	-	<5	0.013	0.49	3.0
2009-05-19	13	9.6	91	7.9	15	0.64	25	340	550	-	13	0.012	0.73	3.5
2009-06-12	14.3	9.6	94	8.0	15	0.61	24	270	470	-	6	0.008	1.00	3.7
2009-07-10	20.5	9.9	110	8.0	15	0.61	16	160	490	-	8	0.016	0.60	3.9
2009-08-19	14.6	8.7	86	7.9	16	0.67	36	110	250	-	26	0.020	1.30	4.4
2009-09-21	15.5	9.7	97	8.0	15	0.66	10	170	380	-	5	0.011	0.55	3.8
2009-10-21	5.4	11.7	93	7.9	16	0.63	14	290	530	-	7	0.014	0.93	3.0
2009-11-19	5.5	11.5	91	7.9	14	0.63	28	460	470	-	11	0.027	0.53	3.9
2009-12-14	1.1	12	85	7.9	15	0.69	63	620	840	-	8	0.011	0.79	2.8
Min 2009	0.8	8.7	85	7.8	14	0.53	10	110	250	-	<5	0.008	0.24	2.8
Medel 2009	8.4	11.2	94		15.2	0.62	32.4	404	578.3	-	7.8	0.013	0.69	3.4
Median 2009	5.7	11.6	94	7.9	15	0.63	24.5	400	540	-	6.5	0.012	0.61	3.3
Max 2009	20.5	13.9	110	8.0	16	0.69	75	770	840	-	26	0.027	1.30	4.4
Medel 2008	9.3	10.4	100		15	0.65	11	504	692	1.5	7.5	0.013	1.48	3.3
Medel 2007	9.2				15	0.64	13	528	754	1.4	5.3	0.022	1.16	3.1
Medel 2006	10.0				16	0.65	24	524	724	1.7	6.9	0.015	2.00	2.9

Table 2. Raw water quality Boren Lake 16th of Feb.2010 (Borensberg Waterworks, 2010)

Analys/Undersökning av	*Resultat*	*Enhet*
Turbiditet FNU	0.26	FNU
Lukt	ingen	
Lukt, art	-	
Färg vid 405 nm	<5	mg/l Pt
Kemisk syreförbrukn. COD-Mn	1.9	mg/l
Konduktivitet 25°C	15.7	mS/m
pH 25°C	7.6	
Alkalinitet, HCO3	39	mg/l
Kalcium, Ca	17	mg/l
Magnesium, Mg	2.7	mg/l
Hårdhet tyska grader	3.0	°dH
Järn, Fe	<0.05	mg/l
Mangan, Mn	<0.02	mg/l
Aluminium, Al	<0.02	mg/l
Koppar, Cu	<0.01	mg/l
Ammoniumkväve, NH4-N	0.070	mg/l
Ammonium, NH4	0.09	mg/l
Nitritkväve, NO2-N	0.005	mg/l
Nitrit, NO2	0.016	mg/l

Table 3. Pure water quality Boren Lake 16th of Feb.2010 (Boren Waterworks, 2010)

Analys/Undersökning av	*Resultat*	*Enhet*
Turbiditet FNU	<0.1	FNU
Färg vid 405 nm	<5	mg/l Pt
Järn, Fe	<0.05	mg/l
Mangan, Mn	<0.02	mg/l
pH 25°C	8.1	
Alkalinitet, HCO3	48	mg/l
Kalcium, Ca	16	mg/l
Magnesium, Mg	2.4	mg/l
Hårdhet tyska grader	2.8	°dH

1.2.2 Water Facility Management

Water facilities in Motala Municipality deal with operation and maintenance of municipal water supply and wastewater handling. The aim is to deliver good quality drinking water with high reliability and disposal of wastewater in a safe manner. The water division is certified by ISO 14 0001 from 2005. More information about Motala's water and environment management can be found at its homepage: http://www.motala.se.

1.2.3 Water Research Project Description

SVU (Svenskt Vatten Utveckling – Swedish Water & Wastewater Association – Research & Development) approved a water research project in Borensberg Waterworks in Sep. 2009, which was cooperated by SWECO AB and Predect AB, aiming to evaluate Predect's new technologies for real-time measurement of water quality and automatic sampling of microbial contamination occurred. It was jointly financed by these three parties and started from Sep. 2009 and lasted for about 12 months.

The goal of this water research was to evaluate Predect's technique that can continuously monitor and document the water quality of raw water and drinking water to detect deterioration of the quality of drinking water before distributing to consumers. Two independent equipments (P-100 and P-300) from Predect AB were installed and connected to the incoming raw water and the outgoing drinking water seperately. In this way, there probably existed correlation relation between variations of particle counts in raw water and the ones in pure water (Predect AB, 2010).

Sudhir Chowdhury who is Predect's Technical and Scientific Director pointed out that the project was mainly focusing on the detection of microscopic pollutants through the correlation between Microbial particles and parasites or bacteria which are in the same microscopic size.

Since viruses need a "host particle" such as a bacterium, to sustain and move. It is probably to correlate the presence of viruses with the microscopic particles in the water. Hence, through collaboration with the Department of Microbiology and Biotechnology at KTH, analysis about the presence of viruses in relation to the detection of contamination has been done (Chowdury, 2010).

Another sister project which have been undergoing in Arboga City is used for horizontal comparison.

1.2.4 Expectations from Predect AB about Borensberg Water Research

1. Let the system work as an early warning system against contaminants and inform the operator. The systems monitor the water quality and immediately detect deviations and record the micro contaminants of the same size as bacteria and parasites such as Cryptosporidium and Giardia.

2. Establish the correlation of microscopic particles with different types of contaminants.

3. Detect contaminants beyond the threshold values and automatically take samples for analyses.

4. Correlation of particle population between raw water and drinking water.

1.2.5 Application of P-100 and P-300 in Motala Water Research Project

Both inflowing and outgoing water in Borensberg Waterworks have been studied with respect to microscopic particles (1-25 microns). In this water research, raw water is the same as lake water (Boren Lake). Two Predect's products（P-100 and P-300）were installed in Motala Water Research Project (Fig.2). P-300 which was installed before the distribution system was working as an early warning system for pure water quality monitoring, continuously recording the particle counts every minutes (24 hrs/day, 7 days/week). P-100 had the same function for the raw water quality monitoring.

The working mechanism for those warning systems are automatically alarming through message with time and date to the operator when the water quality deteriorates with respect to microbiological pollutants and exceeds the THV (Threshold Value). Besides, P-300 in Motala project was investigated for R&D with four different fractions from 1 to 25 Microns (1-2 µm, 2-7 µm, 7-15 µm and 15-25 µm). This is based on potential probability of presence of specific bacteria and parasite. The range can be adjusted and tested in different research project and various purposes. Data related to the particle counting in different fractions are stored and visualized in tabular form for further distribution analysis. At the same time, the real time distribution curve is visualized on the screen shown in Fig.3.

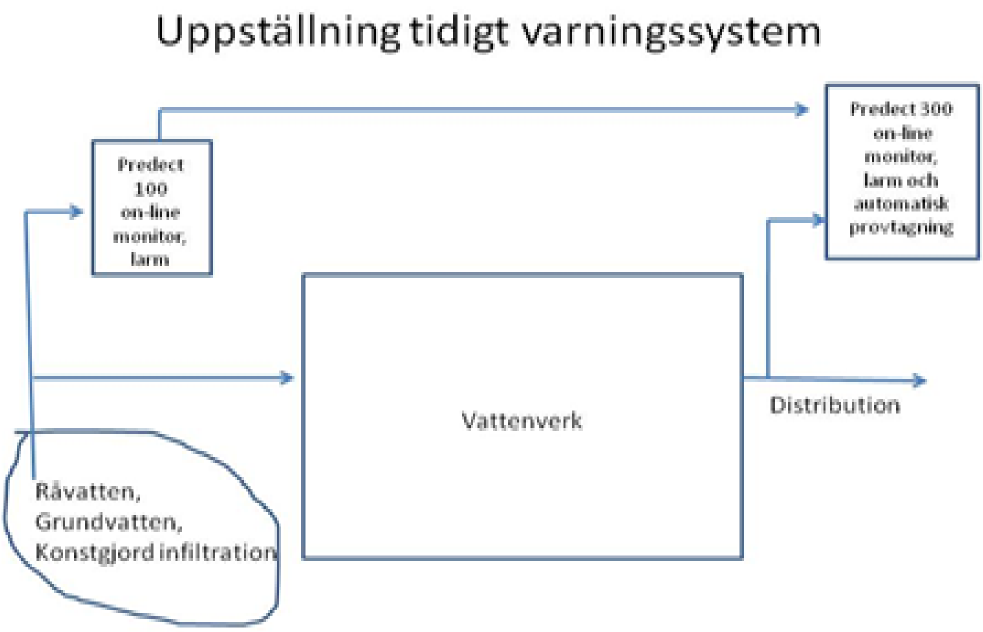


Figure 2. The scheme of water facility with Predect's monitoring system

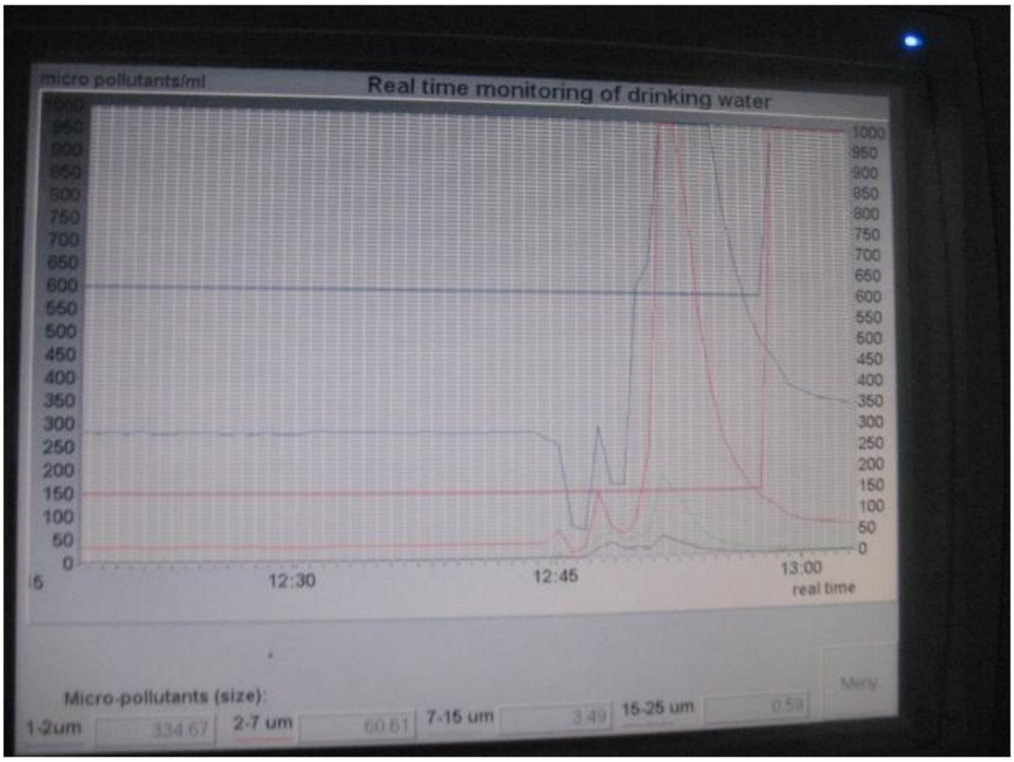


Figure 3. Real time visualization of particle distribution, Borensberg Waterworks, Nov.2010

In this water investigation, measuring principle of extinction was used and the laser-based particle counter instruments were calibrated according to Japanese Industry Standard JIS 9925. The particle counts are Normalized numbers i.e. particles/ml. The flow volume through the sensor is 45-50 ml/min constantly and the sensor detects particles/contaminants of any number.

Water samples which were collected automatically after the THV was exceed, were sent to Biology Lab at KTH for microbiological contaminants analysis through which the water residual and bacteria behavior were deeply studied.

The reason for choosing the range of 1-25 microns for study is that within this size range parasites such as Cryptosporidium and Giardia could be found. They are the common causes of water-borne diseases in surface water sources, groundwater wells and besides, in the surface water sources area, there is of high risk of external contamination due to floods and heavy rain. Furthermore, the water quality in Borensberg Waterworks is influenced by the wastewater discharged near the inlet of the Boren Lake as mentioned.

As a background investigation about size distribution and concentration of the microscopic particles within the range of 1-25 microns in two fractions has been invested in Arboga City in 2010 (Predect AB, 2010).

1.3 Introduction about Related Agencies and Companies

1.3.1 Predect AB

Predect is a Swedish established company, focusing on the applied research, development, and marketing of an Online Water Monitoring and Early Warning System, realizing real-time microbiological contaminants detection and automatic water sample taken of drinking water, reclaimed sewage water, as well as recycled water which could be used in industrial process. This innovation enables immediate action and avoids costly and expensive outbreaks (Predect AB, 2010).

At present, there are three different types of equipments available provided by Pedect AB. They are P-100, P-300 and P-500 for raw water, drinking water and industrial recycled water separately. The typical profile of its products is illustrated in Fig.4.

Figure 4. Profile of Predect's Online Water Quality Monitoring System (Predect AB 2010)

Since having the advantages such as detecting micro-contaminants in real time and collecting water sample automatically, this innovation enables to take action immediately, avoiding expensive pollution.

It works as an early warning system which sets alarms when it detects the abnormal level of contaminants as they are passing the sensor within water flow, alerting the operator through GMS and promote corrective measures to be taken. Furthermore, this could be traceable and recorded by PC. Those functions are all demonstrated in its core technologies shown in Fig.5 (Predect AB, 2010).

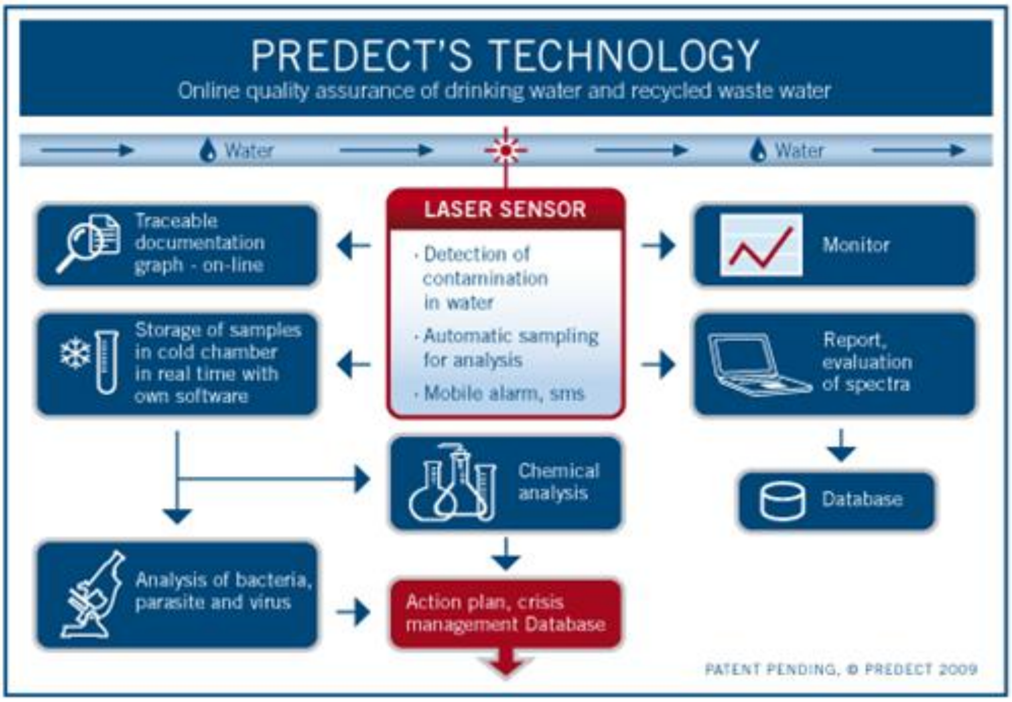


Figure 5. Core technology of Predect' s products (Predect AB, 2010)

A sophisticated laser sensor which is installed in the system transfers and evaluates the light signals from refraction and light extinction through specified software and afterwards the digital signals are visualized as counting on the screen and counting records are generated at the same time.

The laser based particle counting theory and working mechanism will be described in details in methodology part. More information about the products and Predect's technology can be found on its main website: www.predect.se.

1.3.2 Swedish Water Development

Swedish Water Development (Svenskt Vatten Utveckling, SVU) is owned by municipalities for research and development program on municipal water and wastewater technology. SVU focuses on working applied R&D and supporting its members to achieve new research and commission work and encouraging jointed projects. It aims is to promote the development of new knowledge and support the industry's needs for competence. More information could be found through link: http://www.svensktvatten.se/FoU/SVU/.

2 Delimitations

Due to time and financial limits, only particles and microorganisms in the range of 1-25 microns within four fractions in drinking water and two fractions in raw water are detected and monitored. The data available for particle distribution analysis is from Oct. of 2009 to Sep. 2010 without data in some period of time due to server failure when bad GMS transmission occurred.

Practically, real warning system and sample auto-collection were not actually realized during study period. This was partly due to lack of fund for transportation of the collected samples and payment for the workers. Such resulted in high THV set-up and seldom auto-sampling was taken. However it was possible to test its sensitivity and warning function through manual operation during study visit.

Occasionally manual samples were taken from Jun. to Sep. 2010 and investigated at KTH. This provides probability to correlate the particle counts with microbiological population. Unfortunately there was no available data during Aug. and Sep. 2010 from raw water counter due to so high contamination level in raw water that the P-100 had to be stopped because sensors were highly polluted and the level is out of the linearity. Hence, the possibility to correlate the micro-contaminants in raw water and particle counts in drinking water was done with limited data.

3 Aim and Objectives

In order to achieve the best results, the following tasks were planned to be accomplished.

1) Literature study about microbiological water quality detection methods and discuss the possibility to correlate the microscopic contaminants with bacteria and parasites within the same size.
2) Learn about laser meter based particle counter and its working principle and accuracy.
3) Statistical analysis

- Assort particle measurement data and demonstrate the particle distribution through the whole study period and discuss the similarities and difference between raw water and drinking water.
- Detect the correlation between different particle fractions both in raw water and pure water as well as the total particle counts.
- Discuss about the particle size distribution and abiotic parameters such as flow rate.
- Comparison with sister project in Arboga City.

4) Through study visit to test the functions of the system.
5) Suggestions on defining threshold for alarming and auto-sampling.

4 Methodology

4.1 Literature study

In order to understand the development of microbiological water quality monitoring methods, both traditional technique and new innovations such as particle counter are investigated. The possibility to use PSD (particle size distribution) to illustrate microbiological contaminants situation in water is discussed in this sector as well as application and principles on laser based particle counter are presented.

4.1.1 Call for Real Time Microbiological Water Quality Monitoring System

Generally, the traditional way of the microbiological water quality monitoring requires extensive manual sampling and representative investigation sites are chosen for regular water sampling followed by processes such as membrane filtration and by using colorimetric standard to determine the total microbiological pollutants such as E-coli. and Enterococcus etc. (Jean-Luc, 2009).

A basic laboratory establishment would be an advantage but is not absolutely necessary (WHO, 2011). Monitoring microbial water quality relies on sterile water sampling and laboratory analyses. However, lengthy intervals between sampling and the time-consuming process between sampling and its result would not help to prevent contaminated water entering the distribution network (Pronk, 2007). Furthermore, the biggest problem with today's manual sample-rate analysis is that the water is not taken at the right time because operator does not know when the water is contaminated. It always happens that the time when people get sick is the time for detection of the cause. Thus results about 10 days delay of actual measures. Hence, in some instances, with traditional way of microbiological analysis, the problem is detected when people have become sick (Predect AB, 2010).

Consequently, an early-warning parameter would thus be of high significance for drinking water management (Pronk, 2007). It is also suggested by Pronk that continuous PSD monitoring can be used as an early-warning system for fecal contamination of spring water and applicable for aquifer systems with different hydrogeological settings, although local adaptations maybe required (Pronk, 2007).

As a result, a technical tool which has the function to measure the pollutants in the air, water and other materials and help the operator to make decision about the proper purifying methods or corrective measures should be applied. It is reported that one of the most important scientific developments in this concern is particle counter, which can be used to define pollution level with respect to particle numbers (WordPress, 2011). Through measuring suspended solids in water and calculating the removal (reduction) of particles and turbidity difference between raw water and drinking water to verify the effectiveness of water utilities is currently applied (Chowdhury, 2003).

4.1.2 PSD as Surrogate Indicator for Microbiological Contamination

Recently, many studies have been done for investigating and comparing manual counting based particle size distribution and the one done by computer application. One study in 2009 in Germany which compared in-situ particle monitoring to microscopic counts of plankton in a drinking water reservoir showed that light obscuring particle counter (PC) may serve as a helpful tool for management of drinking water in critical situations (Nicole, 2010). During their study, manual counts were compared with the particle size evaluation gained by PC and comparison and correlation between multiple species were applied during the study.

Comparison about Turbidity and PSD was described in one water project in Israel (LeChevallier and Norton, 1995). Study showed that turbidity was not sensitive to particles in the size range of Girdia cysts and Cryptosporidium oocyst due to thousands of particles per milliliter were present in raw water even with low turbidity. Furthermore low turbidity in water after treatment did not necessarily specify their absence (LeChevallier and Norton, 1995). Since these parasites are part of particles in water especially within 1-20μm through many studies and water researches (Chowdhury, 2003). Consequently, there is an increasing trend in monitor and study about water quality by using of total particle counter (TPC) and PSD (Hatukai, 1997).

Particle counter allows PSD to be measured online continuously (Pronk, 2007). During a water research project about karst groundwater aquifer in Yverdon-les-Bains, Switzerland, PSD was deeply investigated by combining PSD, TOC, Turbidity and Discharge and Physiochemical parameters as well as fecal indicator bacteria (e.g. E-coli.) analysis. It provided more insight into the origin and behavior of suspended particles through tracing tests on the dominating pathogen transport process in order to establish the correlation between PSD and the microbiological contaminants in drinking water. It was showed in the result that PSD was indicative of allochthonous turbidity which was the possible presence of fecal bacteria contamination (Pronk, 2007). This means that normalized PSD could be used as surrogate indicator for microbial contamination.

Above conclusions was also assessed and confirmed by Brookes's study on surrogate indicator (PSD) pathogens in lakes and reservoirs. Good correlation between specific particle size fractions and FIB (Fecal Indicator Bacteria) were demonstrated (Brookes, 2005). Another similar method was used in marine bathing water quality study in two marine bathing beaches, southern California. A PSD instrument which applied a light scattering device illustrated the correlation between dinoflagellates and a specific particle size fraction (Ahn, 2007).

Similar study was also done in the consideration of reusing wastewater for agricultural irrigation, in Mexico. In order to comply with the National Standard (Mexico, 1996), the study was focused on measuring the microbial quality of wastewater through correlations between the number or volume of particles and the concentration of Fecal

Coliforms (0.7–1.5µm), Salmonella spp (1.5–4µm) and Helminth ova (20–80µm) carried out. It aimed to determine the distribution of various parameters of water quality (COD,TSS, nitrogen, phosphorous and microorganism) and the particles smaller and larger than 20µm (Chavez, 2004).

4.1.3 Particle size and Microbiological Counts

Since particle number could be used as an indicator for microbiological water quality analysis, the spotlight has begun to focus on a directly measuring device on particle size and population.

Generally, there are three types of particles: inert organic, viable organic and inert inorganic. Technical report from Particle Measuring Systems which is an American company being a world leader in environmental monitoring industry gives out the clear definition of these three particles and the origins of them (Pmeasuring, 2011).

"Inert organic particles come from non-reactive organic material, which is material derived from living organisms and includes carbon-based compounds. Viable organic particles are capable of living, developing, or germinating under favorable conditions; bacteria and fungus are examples of viable organic compounds. Inert inorganic particles are non-reactive materials such as sand, salt, iron, calcium salts, and other mineral-based materials. In general, organic particles come from carbon-based living matter, like animals or plants, but the particles are not necessarily alive. Inorganic particles come from matter that was never alive, like minerals. A dead skin cell is an inert organic particle, a protozoan is a viable organic particle, and a grain of copper dust is an inert inorganic particle" (Pmeasuring, 2011). A common particle size is shown in Table 4.

Table 4. Common particle size (Pmeasuring, 2011)

Particle Content	**Particle Size** (in microns)
Hair	50 - 150 µm
Visible	50 µm
Flu virus	0.07 µm
Pollen	7 - 100 µm
Sneeze particles	10 - 300 µm
Dust	0.1 - 100 µm
Bacteria	1.0 - 10 µm

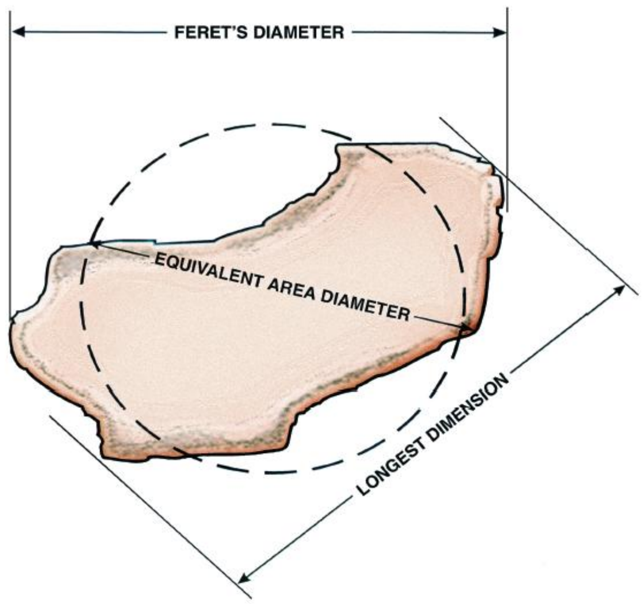


Figure 6. Particle Dimensions (Pmeasuring, 2010)

To measure a particle depends on the measuring methods applied. Fig. 6 shows the standard method. A sphere (equivalent area), simulated below in dashed line, demonstrates the equivalent polystyrene latex sphere. A precise measurement of a number of particles at a nominal size, the distribution follows Normal (Gaussian) distribution. However in reality, particle standards seldom measure the particle size exactly within a particular size channel. Most of the particles are centered at specific size, with some particle numbers larger or smaller than it (Pmearuring, 2011).

Particular bacteria or protozoa may present as particle is feasible. For the most common channels selected are 5 or 7µm (e.g. Cryptosporidium (4-6µm)) and 10 or 15µm (e.g. Giardia (5-15µm)). These two are most critical to drinking water safety for the municipal water industry. The particles larger than 25µm could be related to white blood cells and larger particulates in the water (Hach-lange, 2011). This is also defined in Yokogawa's particle counter which is capable of determining turbid matter containing particles that fall within the range where protozoa such as Cryptosporidium and Giardia present (Urushibta, 2011). In Pronk's study, it also shows that a relative increase of finer particles within the range of 0.9–10µm with respect to a pre-storm reference, PSD is indicative of allochthonous turbidity and, thus indicating the possible presence of fecal bacteria contamination.

The same interest shared by Predect AB was the survey done in 2003 by investigating 17 water utilities at Karlskrona in the South Luleå, North Sweden. Size distribution and the concentration of the particles within the range of 1–20µm were studied in raw water, drinking water and water distribution system by installing its monitoring system. Results showed that PSD could provide information about clear boundaries between different water treatments. And Log. Reduction which was done based on PSD could be used as a useful tool to show the efficiency of water treatment (Chowdhury, 2003). "Log reduction" is a mathematical term (as is "Log increase") used to show the relative number of live microbes eliminated by disinfecting or cleaning.

Still there are challenges such like how to discriminate signals caused by increased microorganism content from the ones coming from increased inorganic particles (Persson, 2009). For example, Pronk's investigation showed that autochthonous turbidity with wide range of particle sizes, including larger particles, the allochthonous turbidity and bacterial contamination periods are all characterized by predominance of finer particles. However, for the absolute numbers, finer particles are always more abundant than larger ones. It is thus necessary to achieve a more advanced analysis of PSD (Pronk, 2007).

4.1.4 Measuring Principles of Particle Counter

Particle counter is an instrument used to collect and analyze particle counts. Its primary applications are mainly focused on two categories: Aerosol particle counters and Liquid particle counters. Liquid Particle Counters are used to qualifying and quantifying the liquid passing through. Hence it can be used to test the quality of drinking water, cleanliness of power generation equipment, pharmaceutical process, and manufacturing etc. By using the same principle, the aerosol particle counters are used for detection the pollutants in the air. The size and concentration of particles can present the cleanliness and determine whether the flow is clean enough for design purpose (RION, 2010).

For particle counting, it is based on either light scattering or light obscuration. The scheme of laser based particle counter is illustrated in Fig 7.

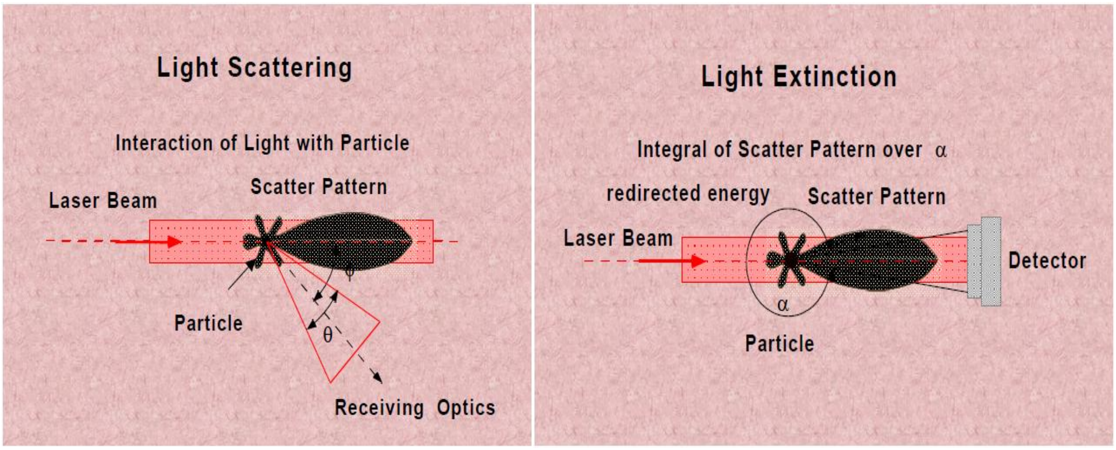


Figure 7. Scheme of particle counter (Available at: http://www.mgnintl.com/pdf/particle_measurement1.pdf)

Mainly, a particle counter comprises Lasers and Optics, Viewing volume, Photodetector and Pulse Height Analyzer. Lasers use diodes to provide high energy light. When the sample medium such as air, liquid, or gas is flowing into the viewing volume, the particles in the flow scatter light as they are illuminated by the laser light. If light scattering is used, then the redirected light is detected by a photo detector. Or if light blocking (obscuration, extinction) is used the loss of light is detected. The photodetector is used to identify the flash of light from scattering or refraction, which afterwards be converted to electric signal pulses followed by using an amplifier to change them to a proportionally controlled voltage (Pmeasuring, 2011). Hence, pluses from photodetector are sent to a pulse height analyzer (PHA) which examines the amplitude of the light scattered or light blocked and puts the values into an appropriate size range which is called bin. The data stored in the bins are correlated to particle sizes. Fig. 7 shows the dealing of scattered light signals where it correlates the pulse number with particle counts and pulse height with particle size separately. An example is shown in Fig.8.

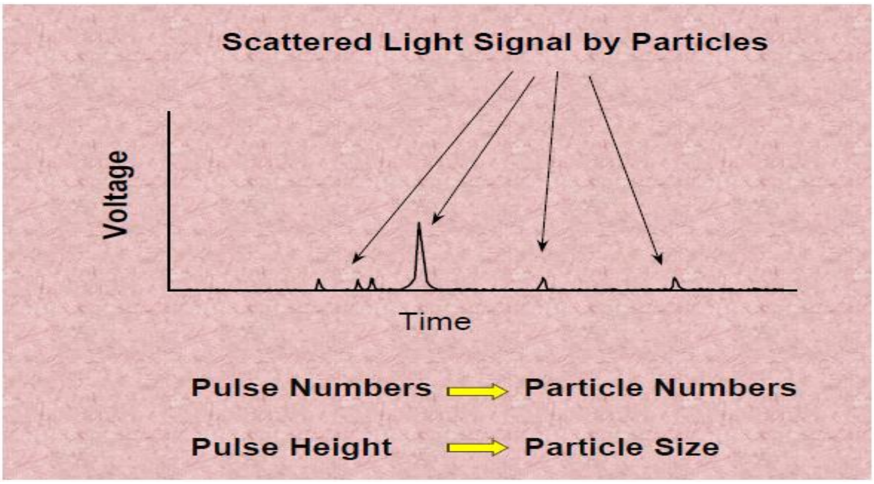
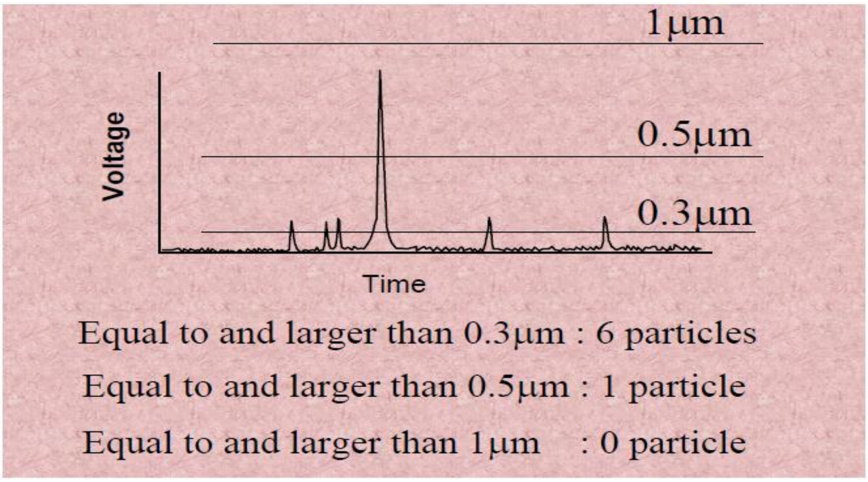


Figure 7. Relations between electric plus and particle parameters (Available at: http://www.mgnintl.com/pdf/particle_measurement1.pdf)

The black box (or support circuitry) is the place where the number of pulses in each bin is examined and converted into digital data. A computer is often used to display and analyze data.

Normally, the Light Blocking Optical Particle Counter (light obscuration) is typically useful for detecting and sizing particles larger than 1μm while for the Light Scattering one is capable of detecting smaller size particles (Pmeasuring 2011).



4.1.5 Key Points of Particle Counter

For a particle counter, there are vital elements to check in advance in order to let it work more accurately and efficiently such as calibration, counting accuracy, resolution, concentration limit and flow rate (RION, 2011).

The standards used for calibration depend on what is used for and the national restrictions, etc. ISO14644 Standards is common airborne particles. USP797 is demanded for pharmacy policies and procedure (U.S. Pharmacopoeia, 2011). The ISO 14698 Standards define two International Standards on Bio-contamination normal control. And for GMP, it is used for rules governing the production, including packing, drug, food and health food.

Generally, for liquid-born particle counter, JIS B 9925:2010 (Japanese Industrial Standard for Light scattering liquid-borne particle counter) is widely used for calibration appliance. There are other standards also largely developed such as ISO 21501 which is a new family of standards describing the instruments and calibration requirements for determining particle size distribution using light interaction methods. It also applies to liquid particle counters (Hach, 2011).

Normally particle counters are calibrated annually or adjusted according to the in-situ situation (Hach, RION, Pmeasuring and Predect AB). Every PODS (precision optical displacement sensor) unit is aligned and calibrated by using the standard required such like JIS B 9925 for Predect AB.

Furthermore, the particle size accuracy of the PODS is assured by using instruments and particle size standards whose accuracy is traceable either to NIST standards (National Institute of Standards and Technology) or to those of comparable national laboratories in Japan (Predect AB).

From investigation on different particle counters available on the market, it shows that the accuracy of them is dissimilar as well. As it is known that laser's intensity is not uniform, which illustrates a Gaussian or bell-shaped distribution where laser is more intense in the center than the edges. Some particle counters apply specific optical masks to visualize only the center part. While most of the counts counted have more or less deviation from the exact numbers. Normally the accuracy varies within different particle size fractions. From technical data about the accuracy of HACH LANGE's particle counter named WPS 21, with PSL (Polystyrene Latex Spheres) for calibration, the accuracy is 20 to 80% at 1μm; 70 to 130% with 2μm and 10% loss at 25,000particles/ml. While for Pharmacia particle counting, Particle Measuring System's products such as APSS 2000 Particle Counter are of great accuracy and be strict with 100+/-10% accuracy rate.

4.2 Statistical Analysis

Normalized value (Particle counts/ml) is used to demonstrate the particle number variation both for raw water and drinking water through the whole study period. Statistical methods were used for data sorting and arrangement. Pearson correlation matrix and regression analyses were applied for analysis of variables of all particle size abundance both in raw water and drinking water.

Log Reduction has been used as a new measure to show the efficiency of water purification. It is reported as a good and simple way to interpret waterworks' efficiency by calculating and visualizing the particle reduction before and after treatment in logarithmic scale. The definition of Log Reduction is given in the Eq. 1.

Log Reduction =-log (Drinking water content / Raw water content) (Eq. 1)

4.3 Numerical analysis

A pure numerical analysis is used for comments about definition of threshold. Estimation of extreme values is used for the probability of events that are more extreme than any that has already been observed and could be used for any kind of extreme values analysis.

Generalized Extreme Value (GEV) Distribution is determined by the following Eq.2.

$$g(z, \mu, \sigma, \xi) = \frac{1}{\sigma}\left[1 + \frac{\xi(z-\mu)}{\sigma}\right]^{1-1/\xi} \exp\left\{-\left[1 + \frac{\xi(z-\mu)}{\sigma}\right]^{-1/\xi}\right\} \qquad \text{(Eq. 2)}$$

Where: z: are the values of your variable

$\sigma > 0$ is the scale parameter

$-\infty < \mu < +\infty$ is the location parameter

$-\infty < \xi < +\infty$ is the shape parameter

Type I: $\xi \longrightarrow 0$ (Gumbel distribution)

Type II: $\xi > 0$ (Fréchet distribution)

Type III: $\xi < 0$ (Weibull distribution)

Parameters such as ξ, σ and μ can be estimated from a fit function named Parmhat=gevfit(x) in Matlab Software. For Gumbel Distribution where ξ is approaching 0, the probability density function and frequency function and the inverse function of interval time are described in Eq. 3 and Eq.4 and Eq.5 separately.

$$g(z, \mu, \sigma) = \frac{1}{\sigma}\exp\left\{-\exp\left[-\frac{(z-\mu)}{\sigma}\right] - \frac{(z-\mu)}{\sigma}\right\} \qquad \text{(Eq.3)}$$

$$G(Z) = \exp\left\{-\exp\left[-\frac{(z-\mu)}{\sigma}\right]\right\} \qquad \text{(Eq.4)}$$

$$\mu = \mathrm{E(Z)can\ be\ estimated\ by\ Z\ mean}$$

$$\sigma = \mathrm{std(Z)}6^{\frac{1}{2}}/\pi$$

Convert Equation 4 to 5 will provide the values of variables by giving different interval time.

$$\mathrm{Z(t)} = \mu - \sigma\mathrm{I}n(-\ln(1-\frac{1}{t})) \qquad \text{(Eq.5)}$$

Where: Z(t): is the return level (return value that you are looking for)

t: is the return period (z is expected to be exceeded once every days)

There is a probability P=$1-\frac{1}{t}$ that z will NOT be exceeded by the maximum in any particular day.

4.4 Study Visit

As part of current research, study visit was vital for field survey, investigation on working conditions of the equipment and its practical test. This practice was held by the end of Nov. 2010, together with a meeting of all the participators involved in Borensberg Waterworks, from which the site background and the treatment process within waterworks, as well as application of Predect’s innovation were deeply studied.

5 Results and Discussion

This section presents differences and similarities of particle counts between raw water and drinking water and their monthly and seasonal variations in terms of normalized values of particle counts through particle size distribution.

Log Reduction is calculated for comparison of total particle counts in two water bodies to test the efficiency of water treatment in Borensberg Waterworks. Furthermore, the correlation between different particle size fractions and the correlation of total particle counts between raw water and drinking water are presented. Also the possibilities to correlate particle counts with microbial counts and variation of physical aspects such as flow are also discussed. Then, comparison of two water research sites is presented to show the equipment's capability of demonstrating the efficiency of water treatment through particle size distribution analysis in different treatment processes. Numerical Analysis method for THV definition is suggested at the end.

5.1 Particle Size Distribution during the Study Period

By assorting the particle counts to the daily average value, the particle size distribution during the study period is clearly demonstrated in the form of graphs.

5.1.1 Particle counting analysis in raw water during study period (Oct.09-Aug.10)

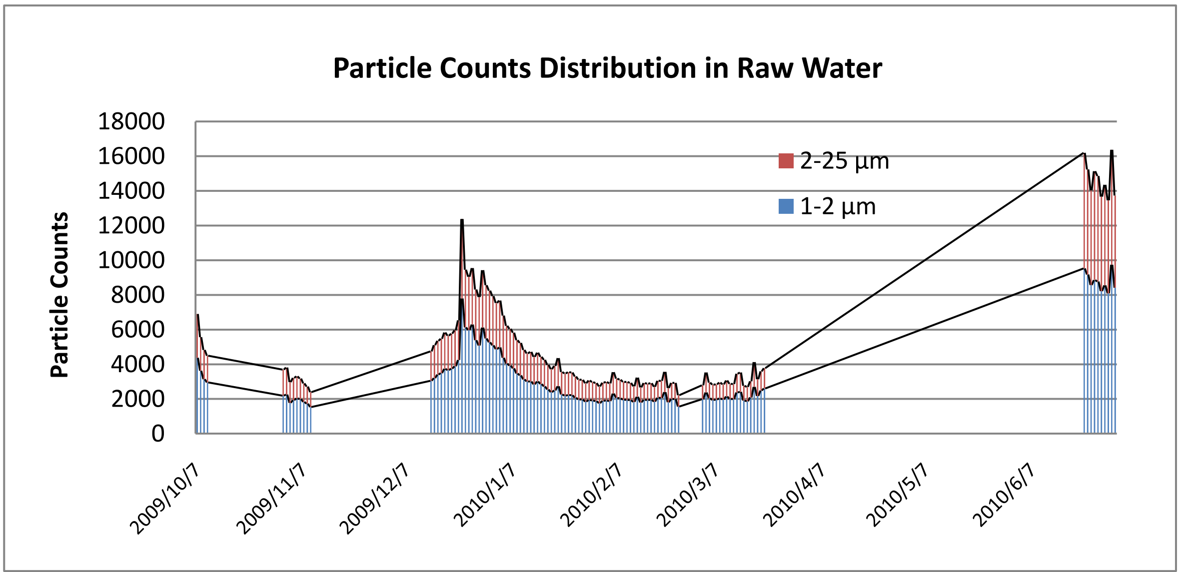


Figure 9.Particle counts variation in raw water based on daily average value (before peak value appeared in July and August 2010)

Figure 9 shows the particle counts in raw water in terms of daily average value from Oct. 2009 to Jul. 2010. There was no data recorded from April to June due to clogging of the equipment caused by high contamination in raw water. High abundance of particle happened in late July 2010 where in the particle fraction size 1-2 µm was exceptionally high while for particle fraction size 2-25 μm was extremely low compared with the values in other months (Fig. 10).

Generally all particle fractions followed the same variation pattern where there was a decrease from Oct. to Nov. in 2009, then from late Autumn it rose up to the first peak in early winter following a drop to a low abundance stage in February from where the rising phrase started again as temperature increases. The seasonal average values of two particle fractions are listed in attached Table 5.

For the "extreme events" in late July and early August (Fig.10), errors or mistakes of operation is first estimated for this unusual behavior. The smaller particle fraction is almost 3-fold higher than larger fraction. Practically, it could happen because that algae blooming always occur in this period of year. As it was studied in microscopic counts in Saidenbach Reservoir, Germany, picoplankton (APP autotrophic picoplankton 0.2-2 μm) which was responsible for the most primary productivity in oligotrophic water bodies such as lake. In that water research the APP fraction ranged about 10-fold higher than larger plankton.

Due to this, in the period of high APP population, the capacity of the particle counter system is easily surpassed in 1-2 μm range (Nicole S. 2010). The high algae blooming is also the main reason for unavailable working of the system P-100 in Borensberg Water Research Project where there was no proper pre-filtration system from April to June, 2011 (Predect AB).

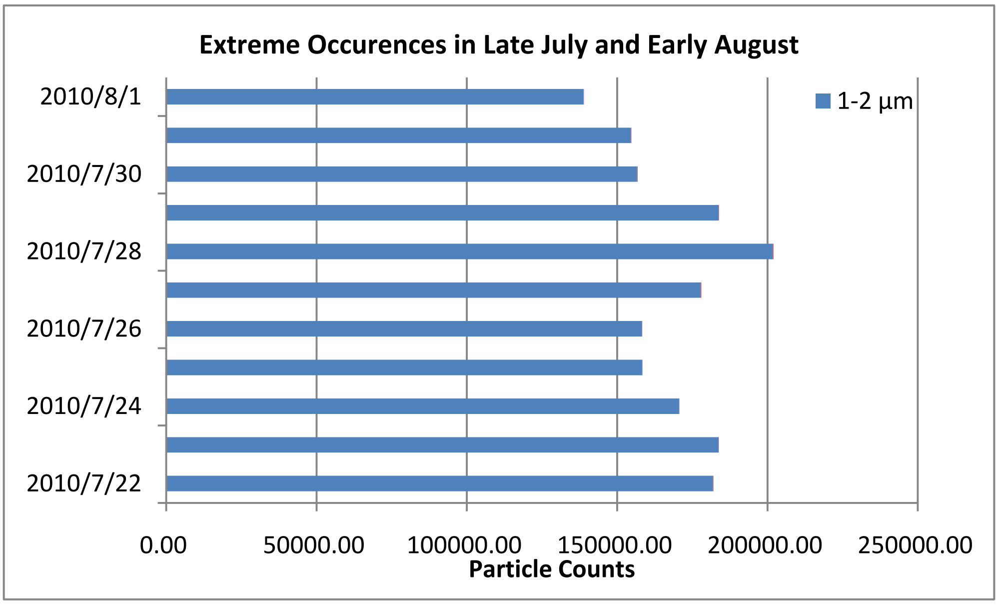


Figure 10. Extreme occurrences in late July and early August where two particle fractions demonstrate quite different behavior, reaching adverse extreme values compared to other months.

Particle composition and variation in raw water

From a monthly average value of particle counts, one can easily find the variation of constituent percentage of two particle size fractions (Fig.11) within total particle number. Except for July and August, particle fraction 1-2 µm in general composes 63% of total abundance with a little negative variation in November and June.

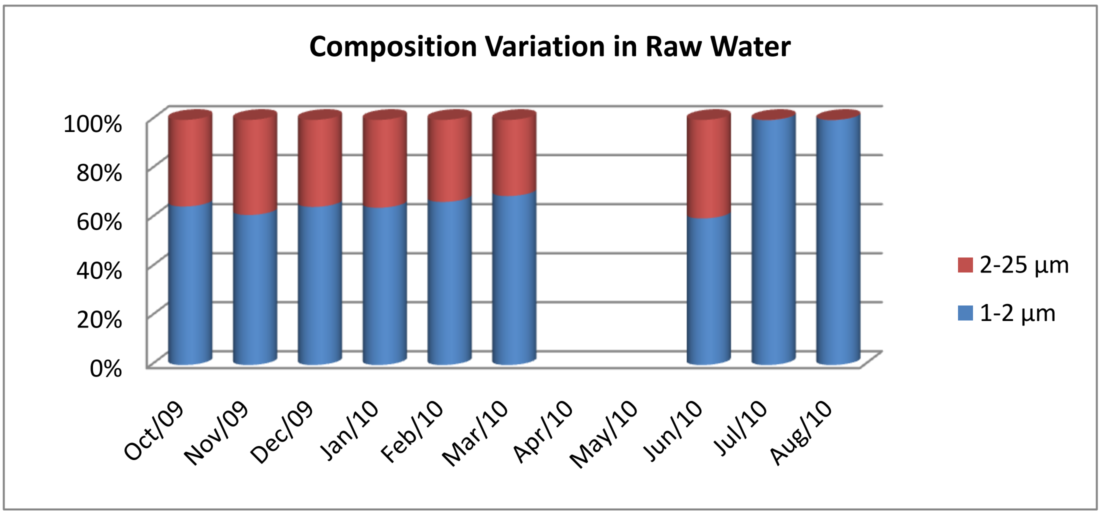


Figure 11. General composition in raw water during the study period shows majority of the particle counts in faction 1-2 µm with instant high value in July and August.

Correlation between two particle fractions

Results of correlation analysis between of the two particle size fractions in raw water demonstrate a high correlation with correlation coefficient as 0.99 (based on daily average value) excluding data in July and August where the value of correlation is 0.88. But from the correlation analysis of these two particle sizes in July and August in attached Table 5 which is based on the minute absolute values, the correlation coefficient which is 0.56. It is of higher correlation after counts being generalized and averaged.

Regression analysis

Regression analysis is based on the daily average value of particle counts. From Fig.12, one can see that the two particle size fractions have good linear relationship. Table 6 is the summery of the analysis which shows a trustable confidence level for the analysis.

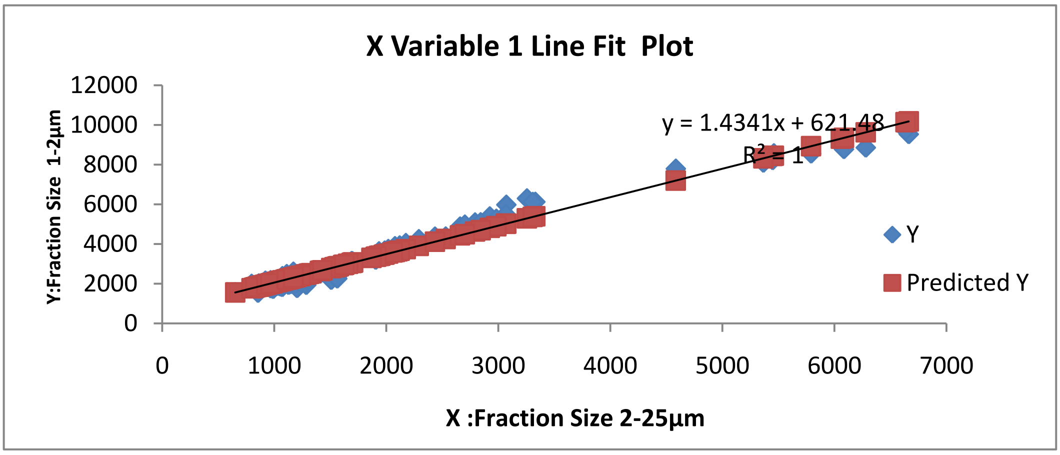


Figure 12. Linear relations between two particle fractions in raw water, Boren Lake

Table 6. Summary of regression analysis of two particle sizes in raw water

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	621,48	49,06	12,66	2,33E-23	524,27	718,69	524,27	718,69
X Variable1	1,43	0,02	68,15	5,10E-93	1,39	1,48	1,39	1,48

5.1.2 Particle counts analysis in drinking water during study period (Oct.09-Aug.10)

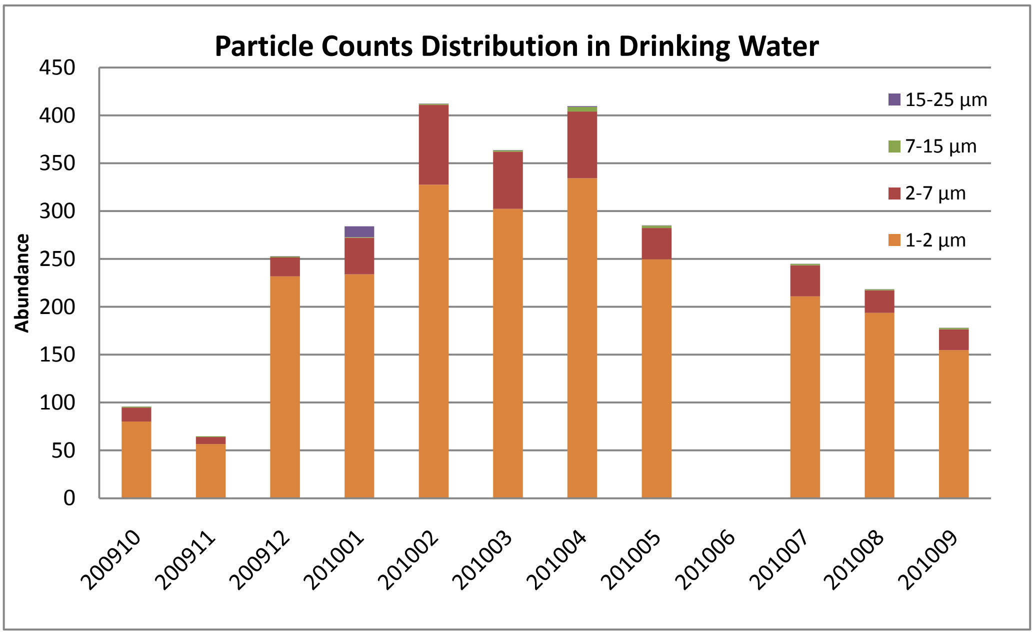


Figure 13. Particle counts in pure water based on monthly average value which shows that high abundance of particles occurred from Dec. 2009 to May 2010.

Fig. 13 shows the particle counts distribution in drinking water during the study period. It clearly illustrates the different variation pattern from the one in raw water after the winter peak period. Instead of decreasing trend of particle counts in raw water in late winter and spring, particle abundance in pure water still remained high value until late spring. It was probably decreasing trend in summer time from estimation of the general variation pattern shown in Fig. 13. The daily variation pattern in Fig. 14 also shows the variation of different particle sizes fractions. Particle counts in drinking water during algae blooming season is undergoing a decreasing phase which shows high efficient treatment process within the waterworks during this season.

Composition variation of four particle size fractions in pure water

The constituent of total particle in pure water and its variation are illustrated in Fig.14 and 15, based on daily average value and monthly average value separately. Different from the particle composition in raw water, particle fraction size 1-2μm occupies almost 85% of total particle counts. Also from the distribution curve, on can find that the particle fraction of 2-25 μm is slightly higher in March and April and the 2-7 μm is the biggest contributor. Furthermore, as mentioned before, the Cryptosporidium and Giardia often present in this microscopic range. Probably the nutrients from the bottom of the lake were brought into the water body and used for growth of the bacteria in this range.

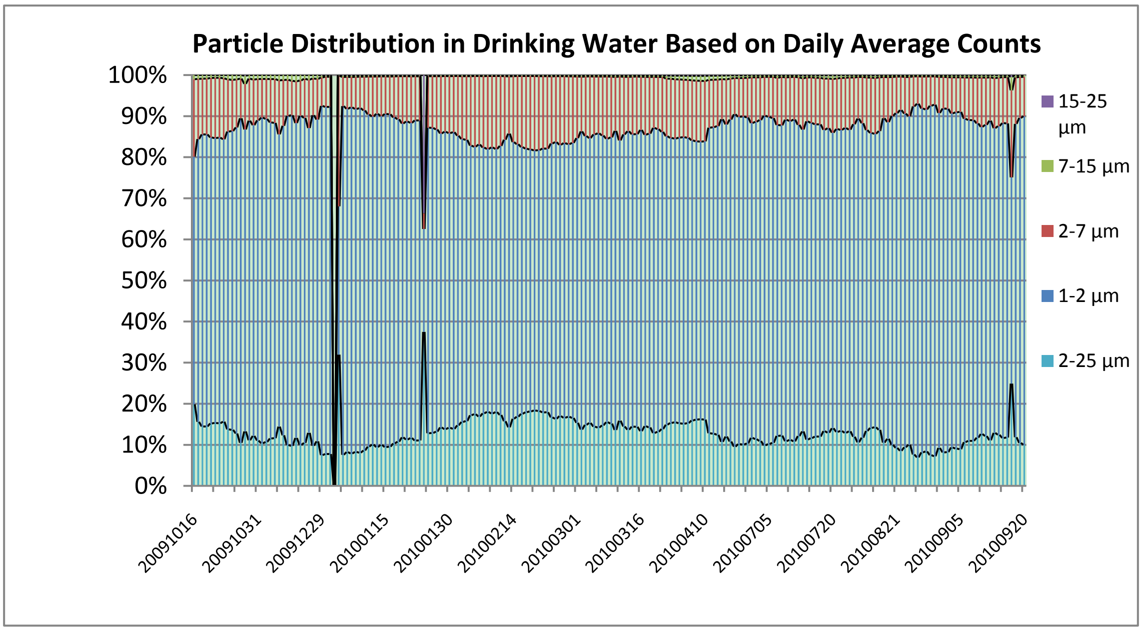


Figure 14. Particle counts constituents in drinking water based on daily average abundance

(Two stochastic accidental events happening in 20100101 and 20100124, just one minute record without any correlation between former or latter counts)

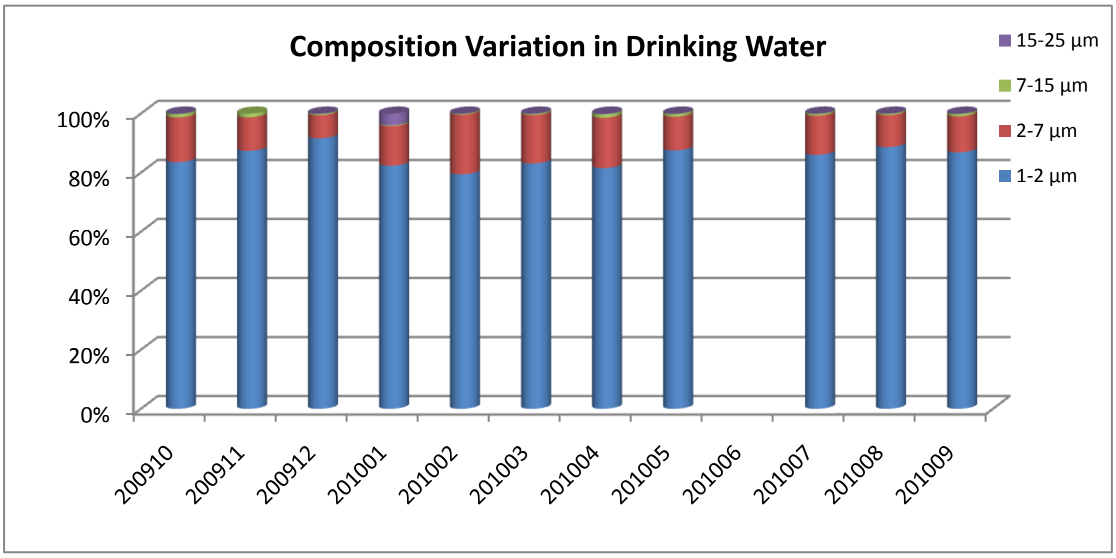


Figure 15. Constituents of particle fraction and their variation based on monthly average value

Correlation of different particle size fractions in drinking water

Correlation matrix of five different particle size fractions in pure water is shown in Table 7. The value of correlation factor between 1-2 µm and 2-25 µm is 0.63. It means certain good correlation between these two particle fractions, although it is not as good as the case in raw water. There is good correlation between particle fraction 1-2 µm and 2-7 µm that probably is useful for consideration of particle fraction separation in the future study. Perhaps same type of microbiological contaminants is within the range of 1-7 μm.

Table 7. Correlation matrix of particle size fractions in drinking water during the study period (based on daily average value)

CC.	1-2 μm	2-7 μm	7-15 μm	15-25 μm	2-25 μm
1-2 μm	1				
2-7 μm	0,787843	1			
7-15 μm	0,28559	0,266591	1		
15-25 μm	0,010629	-0,00992	-0,03921	1	
2-25 μm	0,631043	0,783321	0,216022	0,61304	1

5.2 Comparison between Lake Water and Pure Water

The relation between particle size fractions in raw water and drinking water is of great interest in this study. By selecting the time period where both data of particle counts in raw water and drinking water are available, the Log Reduction of particle amounts is computed and the possible correlation between particle fractions are investigated.

For surface water treatment rule described in Hatukai's study in Israel, the principles of surface water treatment are 99.9% (3 logs) removal or inactivation of Giardia) or 99.99% (4 logs) removal or inactivation of entire viruses (Hatukai,1997). Furthermore, an ideal Log Reduction for a waterworks was suggested as 3 logs in term of microscopic particles from previous research in 2003 by Chowdhury.

Since, Log Reduction has been improved to be a valuable method for risk analysis of probable microbial and parasitic contamination of drinking water (Chodhury, 2003). It is suggested to use Log Reduction as a vital tool to demonstrate the removal of particle number in water treatment process as well as the efficiency of specific Waterworks. However it must be noticed that the absolute values of microscopic particles/ml should be basic guideline for the Waterworks (Chowdhury, 2003).

By using Log Reduction method in this research project, it clearly shows the reduction of particle counts between the raw water and the pure water in Fig.16. In general, the Log Reduction is 1.05 while in late July it was 2.82logs due to algae bloom. However, the high Log Reduction value in summer time is due to the high pollution level in the raw water.

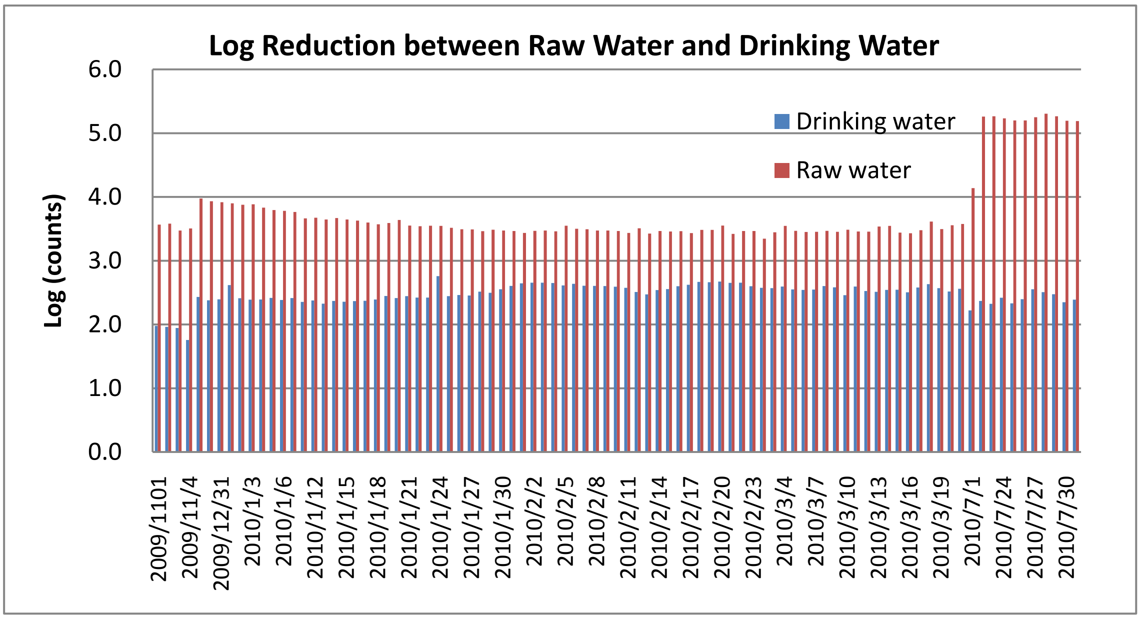


Figure 16. Particle counts distribution in the form of log during the study period (from which one can find the reduction of particle abundance in water before and after Borensberg Waterworks)

Results demonstrate that water treatment within the waterworks meets the treatment requirement in general in summer time while in other months; since the Borensberg's waterworks has a downstream ultraviolet disinfection, the need for improvement of treatment process is not critical.

5.2.1 Correlation of Particle Counts between Raw Water and Drinking Water

Interesting correlation of all particle size fractions in drinking water and raw water during different study periods has been detected carefully. In a general point of view (e.g. correlating data over whole study period), there is less or even no relation between the total particle counts in those two water bodies. However, further correlation based on a daily average value, Pearson Correlation matrix varies in different months. The results are illustrated in the Attached Table 8.

In Nov. 2009, there is weak correlation between some particle fractions. While for correlation matrix in Dec. 2009, all the particle fractions and total abundance are highly correlated excluding the smallest particle fraction size (15-25 μm) where there is almost no count at all. Attached Tab. 8 also shows that there seems a correlation transition from one particle fraction size to another during some period of time such as January in which correlation varies as temperature is getting colder. Along with the deep winter is coming, the correlation becomes weaker. New and interesting correlation started in March 2010 present in particle size fractions 7-15 μm and 15-25 μm. If more data provided, the correlation could be of great interest during the spring stratification period. Nevertheless, a simple assumption could be that correlation coefficient is increasing from April to June since good correlation between all fraction sizes in July. However this needs further investigation. Thus the correlation probably has a seasonal or monthly variation from current investigation. Although this variation is not clear so far, it could be done by analysis with more abiotic parameters such as TOC or Turbidity. More and further investigation is needed in this study. Probably this kind of study could be referred to microbiological activities or growth of bacteria.

5.2.2 Regression analysis

Linear plot and regression analysis (Fig.17 and Tab.9) is made to demonstrate the correlation between of total particle counts in raw water and pure water. No clear linear relation exists between total particle counts in raw water and drinking water.

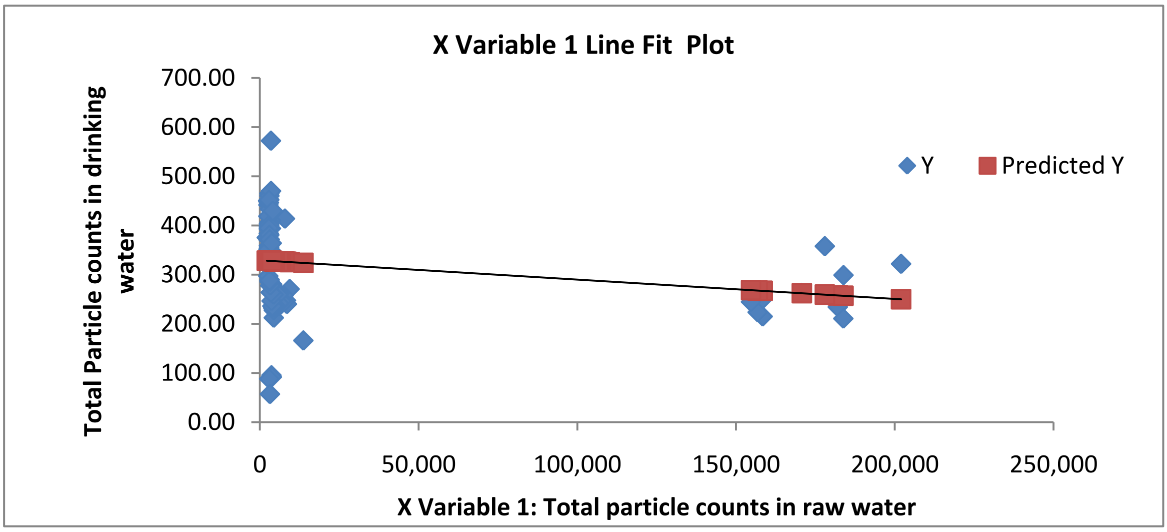


Figure 17. Linear relations between particle abundance between raw water and drinking water

Table 9. Summary of Regression Analysis

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	329,32	10,78	30,545	2,79E-48	307,8926	350,75	307,89	350,75
x variable1	0,00	0,00	-2,128	0,036143	-0,00076	-2,6E-05	-0,00076	-2,6E-05

5.3 Possible Correlation between Particle Counts and Microbial Counts

Current microbial counts analysis is shown in Fig. 18 (Predect AB). The study of correlation between particle counts in raw water and the microbial contaminants would be of high interest.

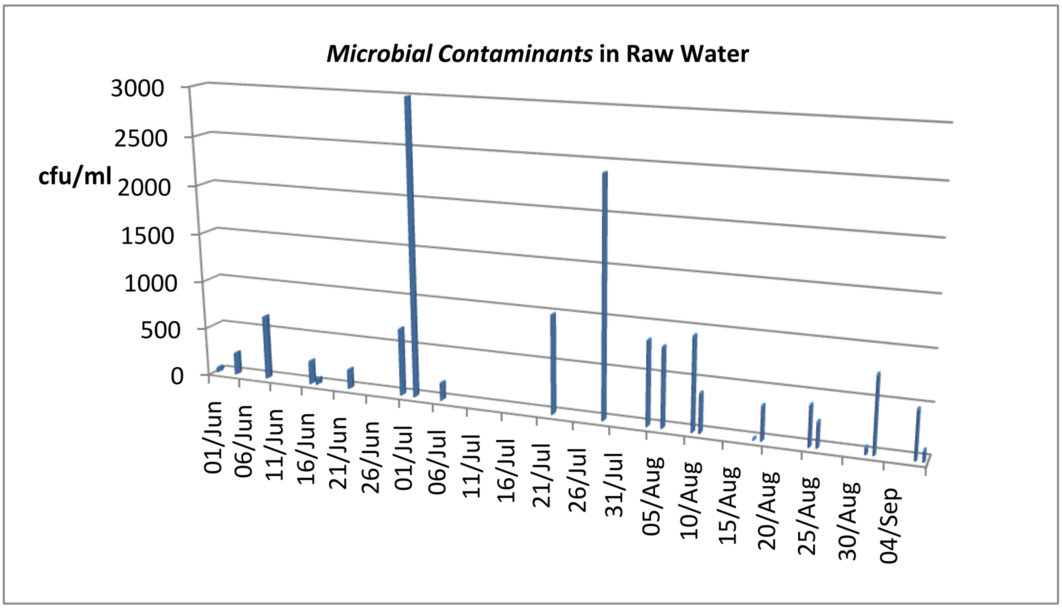


Figure 18. Microbial contaminants in lake water, Boren Lake (Sources from Predect AB, 2010)

Unfortunately, due to high contamination level in the source water and other uncertainties in trial stage of the equipment P-100, corresponded data about the particle counts in raw water is not enough to build up the correlation between the microbial contaminants and particle counts. Consequently, researchers tried to find more possibilities to correlate the drinking water quality and the microbial contaminants in raw as follows.

The abundance of total particle number in drinking water during the sample taken period is within the range of 150 - 300 per ml (Fig.19). The correlation between the total particle counts in drinking water and microbial contaminants in raw water is illustrated in Fig.20 which presents weak correlation. Hence there is indirect weak relation between microbial counts in raw water and particle counts in drinking water based on current study. Further investigation is suggested by analyzing more available data in the future.

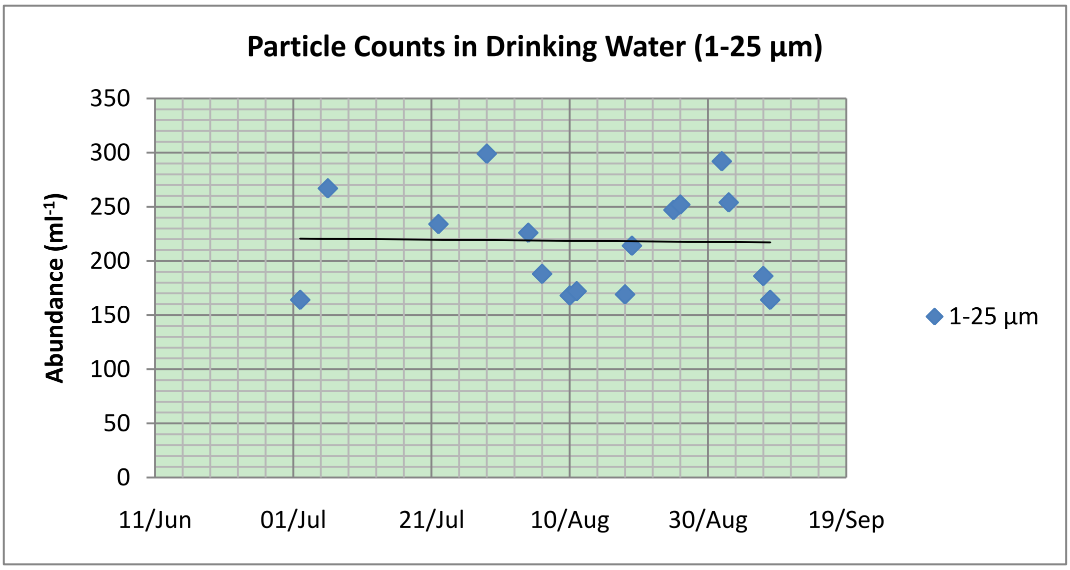


Figure 19. Scattered total particle counts in drinking water during sample taken period

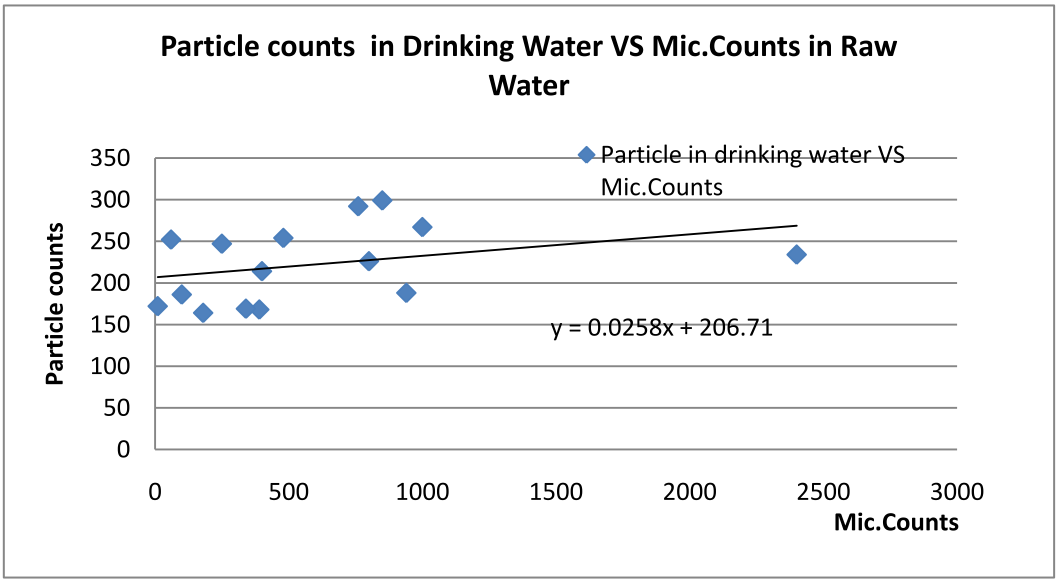


Figure 20. Correlation between particles counts in drinking water and microbial contaminants distribution during sample-taken period

5.4 Possible Correlation between Abiotic Parameters and Microbial Contaminants

Due to Boren Lake is located downstream of Vätten Lake, the outlet flow rate of the lake (Fig. 21) can be regarded as the inflow of Boren Lake. This aims to investigate the connection between the flow and contaminants counts in raw water. Result in Fig. 22 illustrates weak correlation between them. Since based on weekly data, this is not a good way to present actual situation. If the daily flow data is available, it could be more accurate. In general, there exists weak negative relation between particle abundance and flow rate.

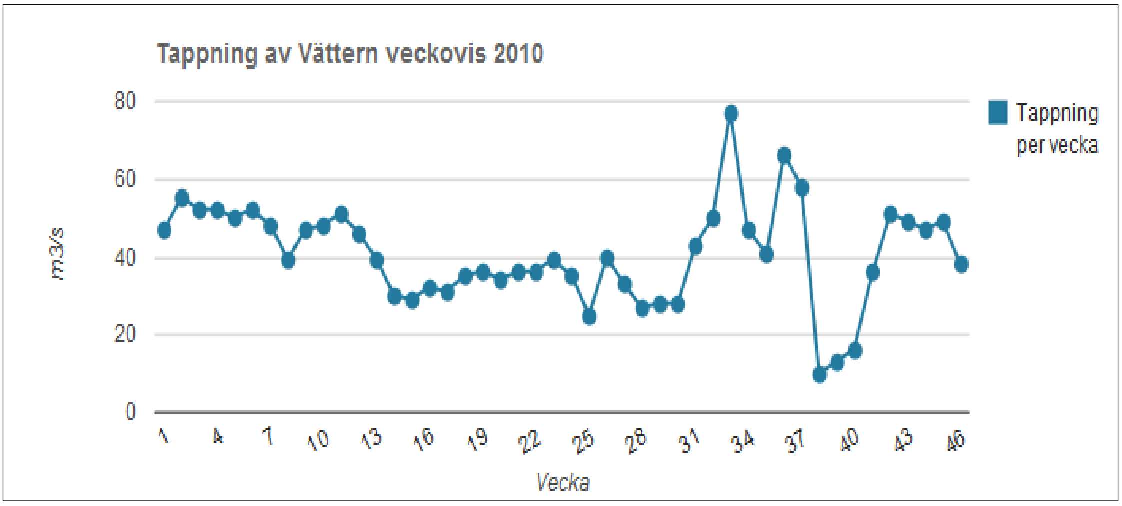


Figure 21. Outlet flow rate of Lake Vätten (source : http://www.tekniskaverken.se/matvarden/vattenreglering/vattern/)

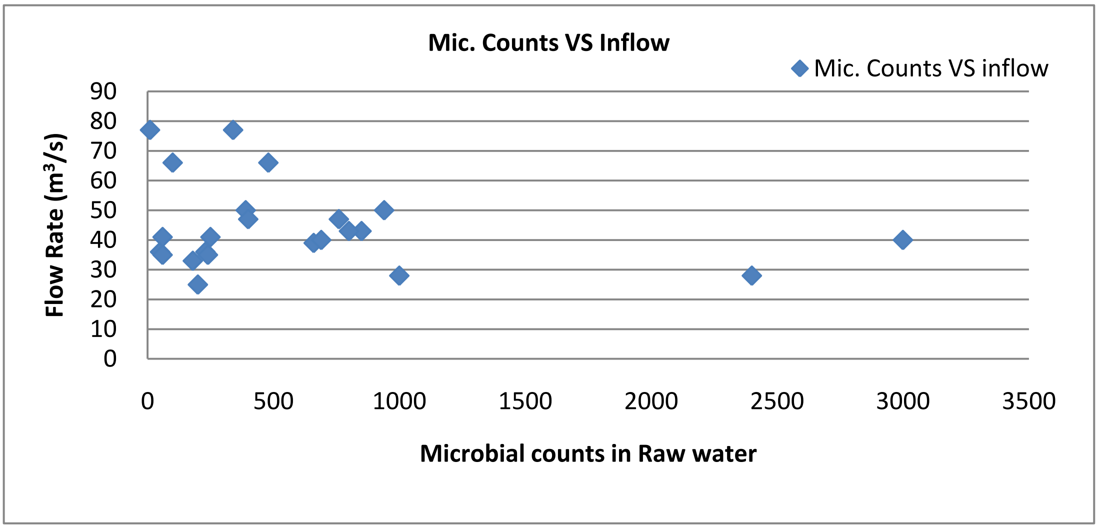


Figure 22. Correlation between flow and microbial contaminants in raw water

Through investigation of pH value through whole study period, it remains within the range of 7.8 to 8.0. So it is more interesting to find other parameters for analysis. Since temperature varies from near 0 to 21° C through the year, particle counts may have some relation with particle concentration. Moreover from seasonal distribution, there would be more interesting research to go deeper. However, from current available data, there is no direct correlation between temperature and particle abundance.

5.5 Results from Study Visit

A test for early warning function of the equipment was done by using P-300 at Borensberg Waterworks. Results showed that:

1) P-300 is able to count the number of particle in all particle size factions (1-2-5-7-15-25μm).
2) It works on line in real time.
3) It can alarm when the value surpass the threshold value.
4) It collects samples automatically in the container (500ml) located in the lower part of the equipment when it is alarming.
5) At the same time, it sends message to the operator with time and values of the events.

5.6 Horizontal Comparison with Arboga Water Research Project

Horizontal comparison of treatment efficiency between different water plants with dissimilar treatment processes could be made through comparison of particle distribution. This research was supposed to present a method through visualizing particle distribution for this kind of analysis.

Along with the water research in Borensberg, a sister project by applying the same Predect's particle counter P-300 was undergoing in Arboga municipality where surface water (lake) was used for water sources. The system P-300 was installed before water distribution system. Two particle fractions 1-2 μm and 3-25 μm were counted by the particle counter. Compared with Borensberg Waterworks the difference was that an advanced continuously moving sand filter was used in Arboga which provided higher treatment efficiency.

This is obviously visualized in the particle distribution curve (Fig.23) compared with the one in Borensberg Waterworks (Fig.24). Generally, the average of particle counts in Arboga is around 50 while the number in Borensberg waterworks is 266 during the same period of time. The obvious high peak in late Jun in Fig.23 was caused by the regular cleaning operation of sand filter (Chowdhury, 2011). The less of the particle population detected the larger extent it indirectly represents the quality of the water which goes into the distribution system.

Results from particle distribution analysis of two similar sized water plants with different treatment process show that P- 300's in time records of particle population could be used for horizontal comparison of efficiency of treatment in the waterworks. Because the only difference between these two Waterworks is the filtration process, it is apparently to evaluate the particle counts reduction by using the moving bottom sand filter compared with a traditional stable one. For the running of water treatment plant, it would be an interesting practical usage.

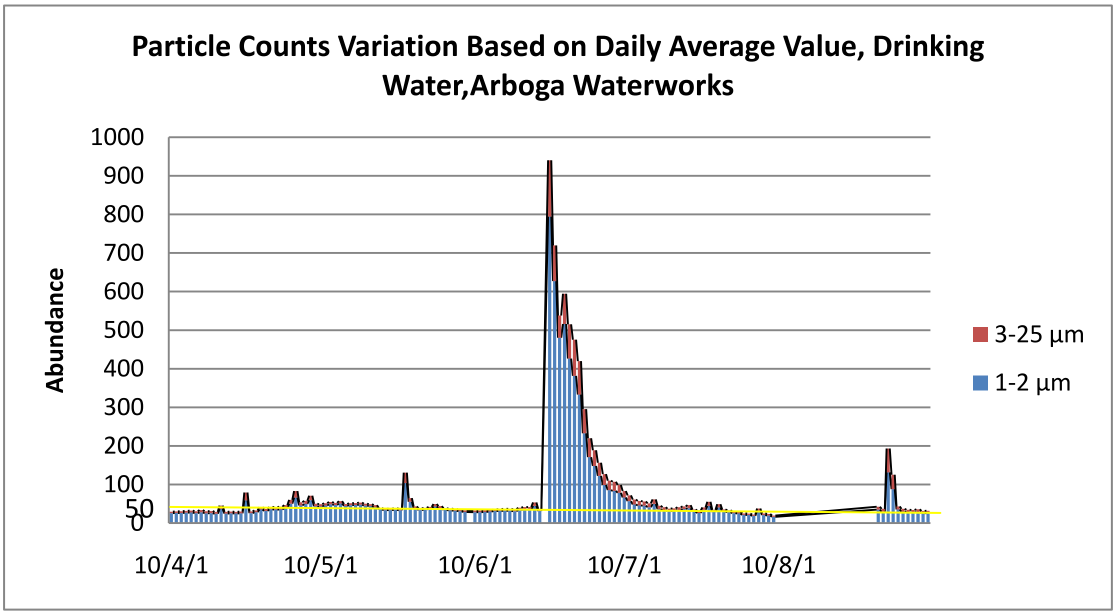


Figure 23. Particle abundance distribution in pure water in Arboga Waterworks 2010. Yellow line is the total average value of particle counts.

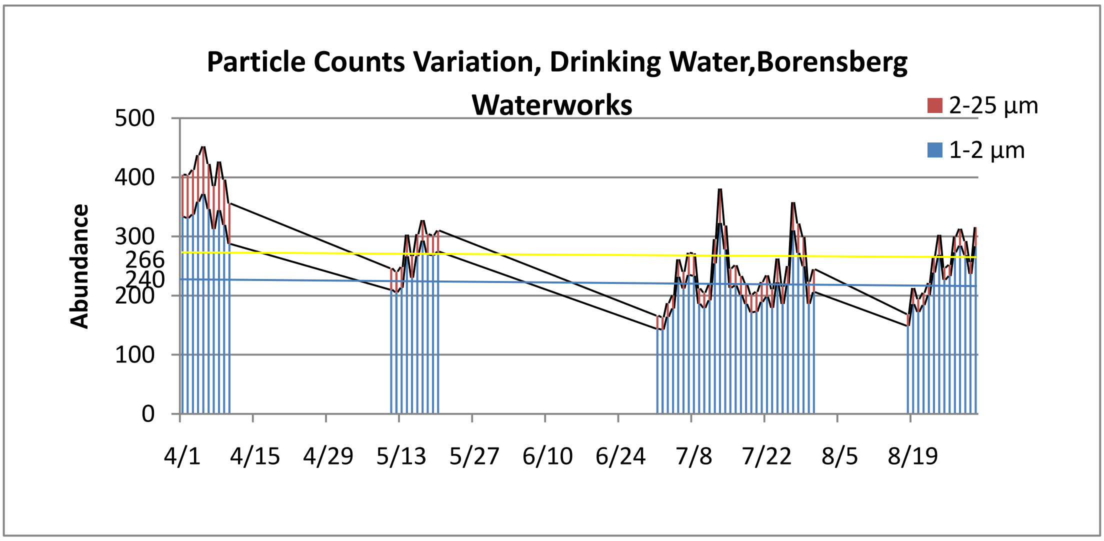


Figure 24. *Particle abundance distribution in pure water based on monthly average value (Yellow line shows the average of total abundance and the blue line is the average counts of fraction 1-2 µm)*

However, this analysis is confined within the study period; it is unavailable to make analysis of the comparison of the particle distribution in the same time through different years. If this online in time monitoring will continue for a long run, a vertical analysis could be used to provide much more information about the performance within the water treatment plant, providing support for the utility manager to adjust the treatment process and control the whole water supply system.

5.7 Suggestion on Defining Threshold Value

Generalized Extreme Values (GEV) distribution was introduced in threshold definition analysis. This aims to provide proper method for threshold set-up and discuss the probability to control auto-sampling. The process of analysis of defining threshold for particle fraction 1-2 μm in drinking water is depicted in details as an example in this section.

The first step is to pick up the daily peak values through the whole study period. parmhat=gevfit(x) in Matlab is applied to define the shape parameter (ξ), scale parameter (σ) and location parameter (μ). For the fraction 1-2 μm in drinking water, there are 208 values in total used for extreme value analysis. The parameters of shape, scale and location are 0.29, 112.44 and 177.66 respectively. Since 0.29 is approaching 0, Gumbel distribution is applied.

Results of probability Density Curve and Cumulative Frequency Curve are demonstrated in Fig. 25 and Fig. 26.

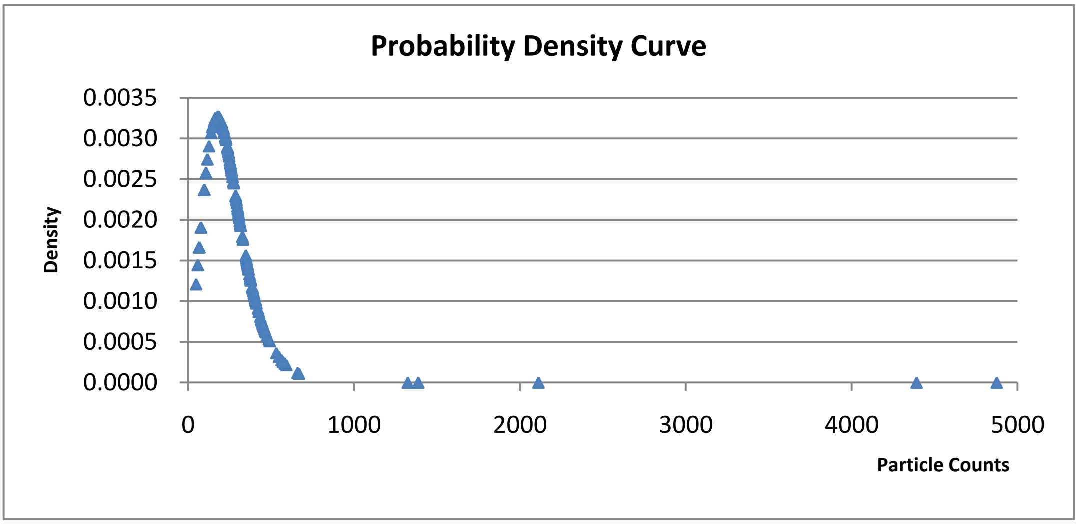


Figure 25. Gumbel probability distribution of particle fraction 1-2 μm in drinking water, Borensberg Waterworks

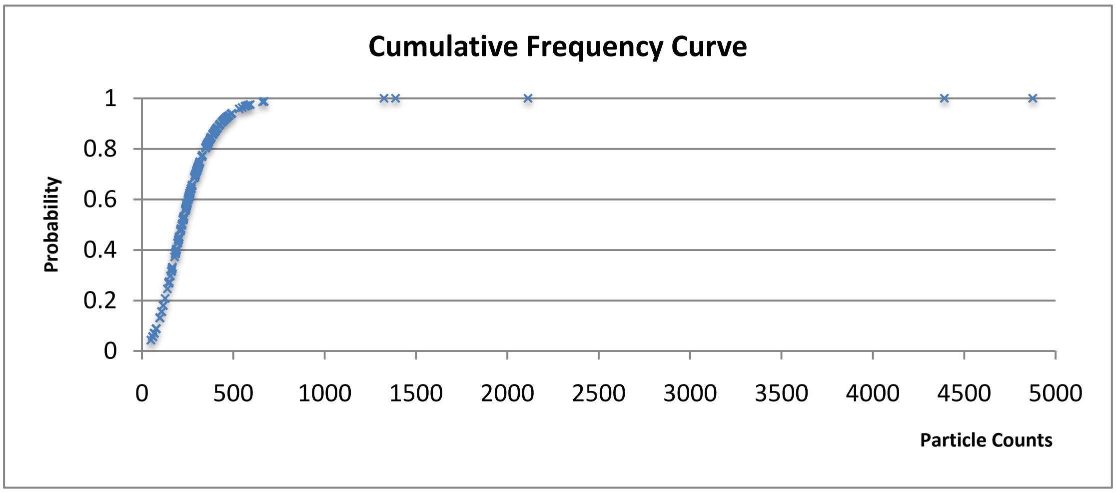


Figure 26. Cumulative Frequency Curve of particle fraction 1-2 µm in drinking water, Borensberg Waterworks

For analysis of interval period for a specific value, Fig. 27 is functional to realize the particle abundance recurrence time and its frequency.

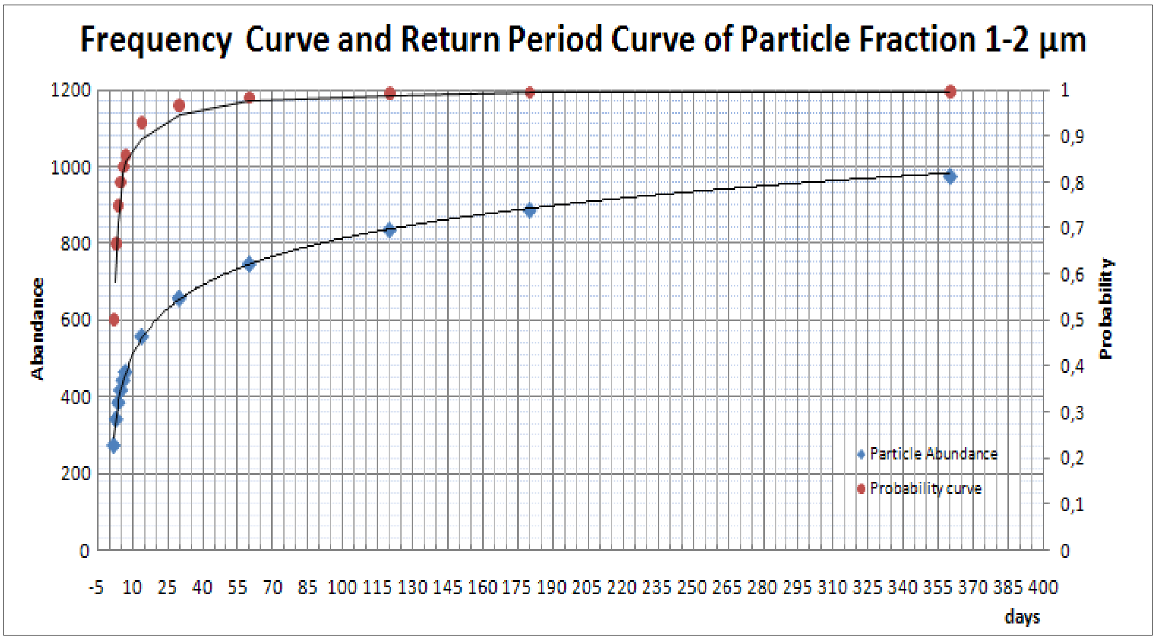


Figure 27. Frequency Curve and Return Period Curve for Particle threshold value definition of Fraction 1-2 µm in drinking water, Borensberg Waterworks.

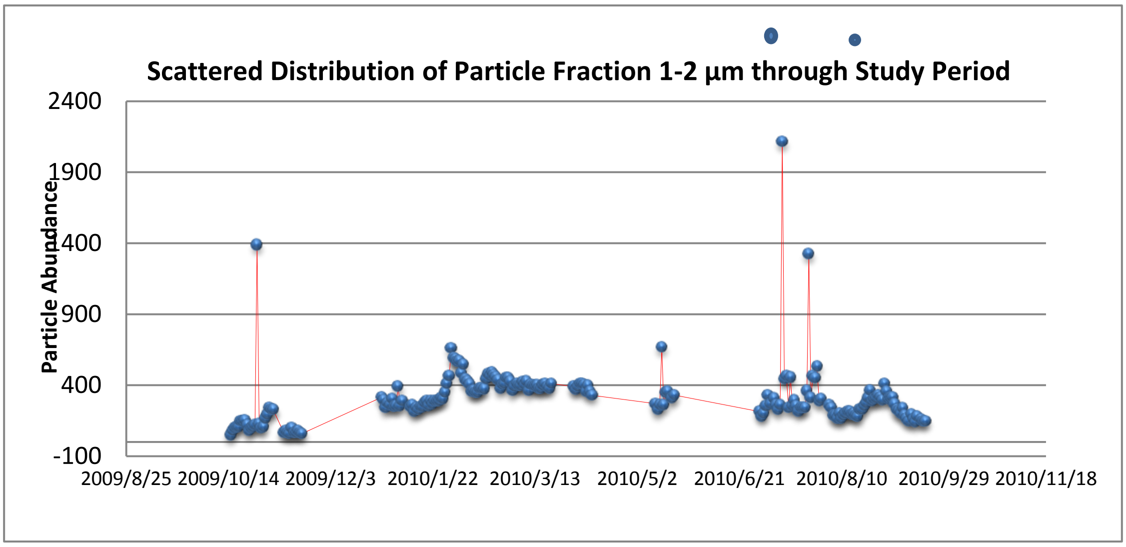


Figure 28. Scattered distribution of particle fraction 1-2 µm in drinking water, Borensberg Waterworks.

Numerically, from the Density Function Curve shown in Fig. 25, the particle counts of 700 is at the +2σ range edge where 98% of the series is. It means that the chance for the number over 700 to present is around 2% which is also the same probability checked in Fig.27. Meanwhile the frequency interval for 700 is 60 days reoccurrence read from Fig.27. Those events occurred are regarded as stochastic events in our case. Probably, it may demonstrate potential higher risk of microbiological pollution and also it could be caused by system error.

Set-up value of 460 is probably a proper start point of auto sampling suggestion, because the abundance which is over this amount has 10% chances to happen. High risk group should be mostly considered for further laboratory analysis. This would probably include the seasonal circulation influence and its reaction on the microbiological population. Because the particle concentration is higher during spring time as well as the algae booming season from scattered particle distribution curve in Fig. 28, this will bring frequent sampling.

It could be more practical to adjust the threshold during different seasons since particle population is unevenly distributed over the year. From study of deviation from the average seasonal value, the suggested boundary line shows that this threshold value is probably a good parameter for winter, spring and summer time, but for autumn, adjustment is needed. The suggested threshold value of 460 is about 77%, 53% and 119% higher than the average value in winter (260), spring (300) and summer (210) respectively. While for the autumn when the average value for the particle is about 70, the advised value surpasses about 557% more. It seems that this set is set too high for this period of time with quite few sampling.

Moreover, it is uncertain about other influencing factors hidden e.g. whether it is due to seasonal fluctuation or the microbiological activities is a question. The lower particle abundance could have high potential risk as well. But as a general point of view, the higher the particle concentration, the more potential microbiological pollution risks it is.

As conclusion of extreme events analysis for particle fraction size 1-2 µm, a comparatively proper value for Borensberg Waterworks is suggested as 460 for a trial test. Adjustment should be done with practical laboratory analysis especially in autumn when there are less particle counts present. Because until now there is no clear evidence to show that low particle concentration means less microbiological pollution risk.

By applying the same method, the suggested value for warning and sampling of fraction 2-25 µm and total amount of the particle within 1-25 µm could be made. The value of 119 and 600 are advised separately for the warning level of 2-25 and 1-25 µm. Fig. 29, 30, 31 and 32 are the results for the particle size fraction 2-25 µm and Fig. 33, 34, 35 and 36 are for particle size fraction 1-25 µm.

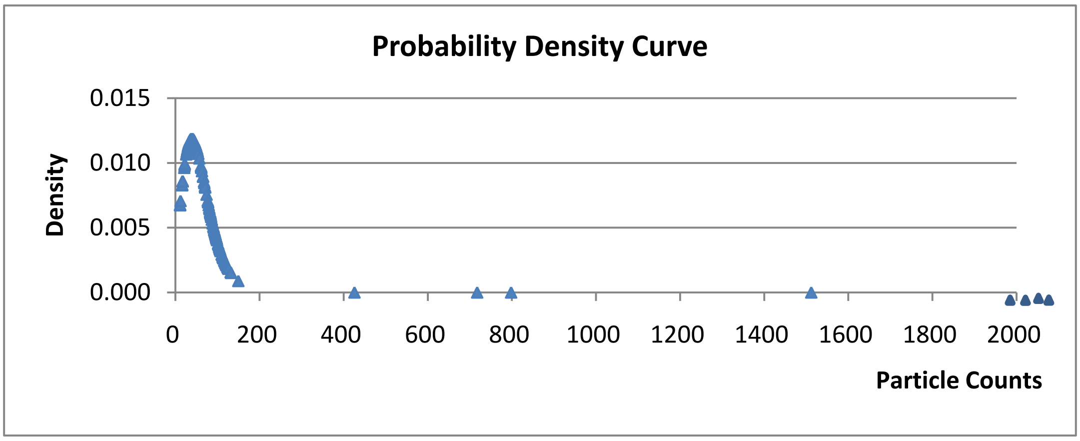


Figure 29. Gumbel probability distribution of particle fraction 2-25 µm in drinking water, Borensberg Waterworks.

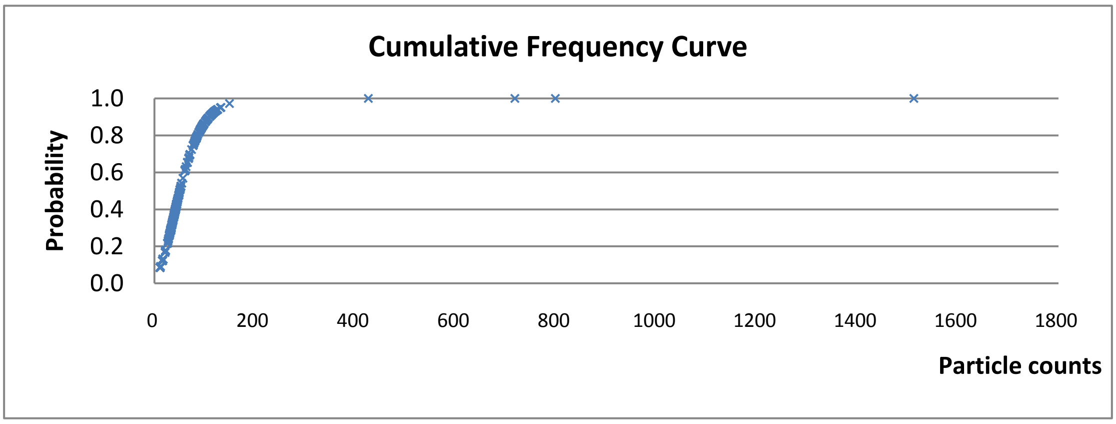


Figure 30. Cumulative Frequency Curve of particle fraction 2-25 µm in drinking water, Borensberg Waterworks

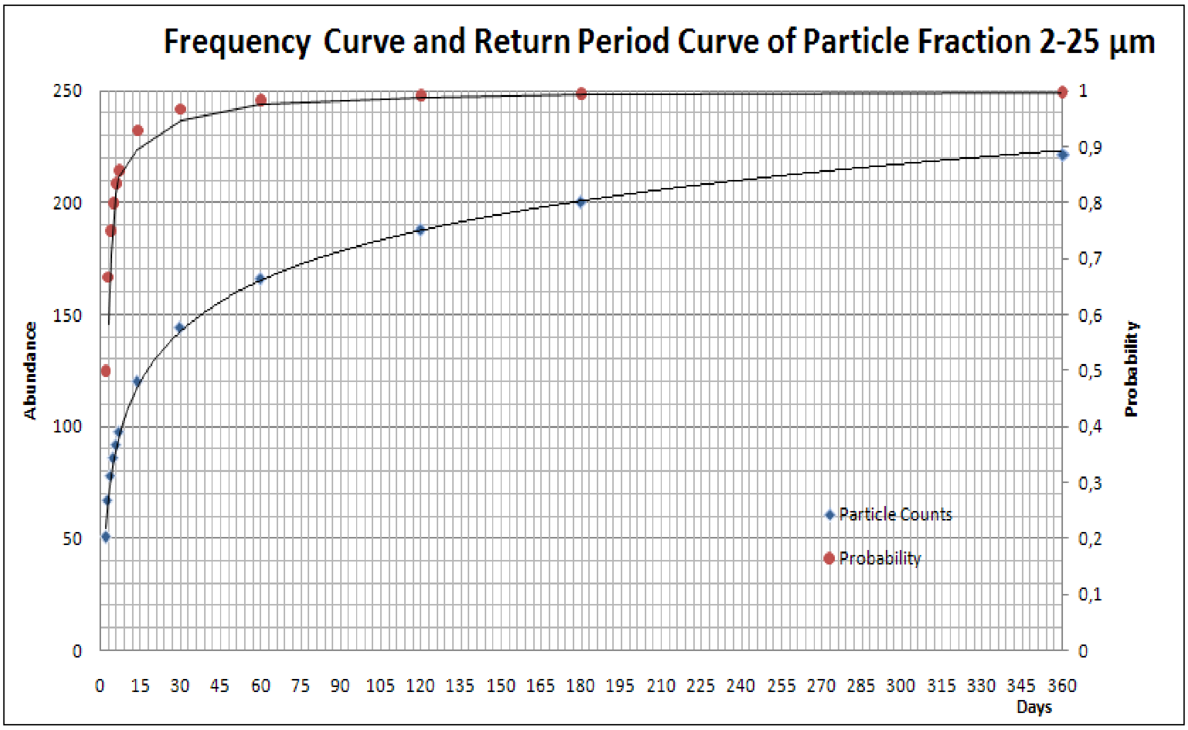


Figure 31. Frequency Curve and Return Period Curve for Particle threshold value definition of Fraction 2-25 µm in drinking water, Borensberg Waterworks.

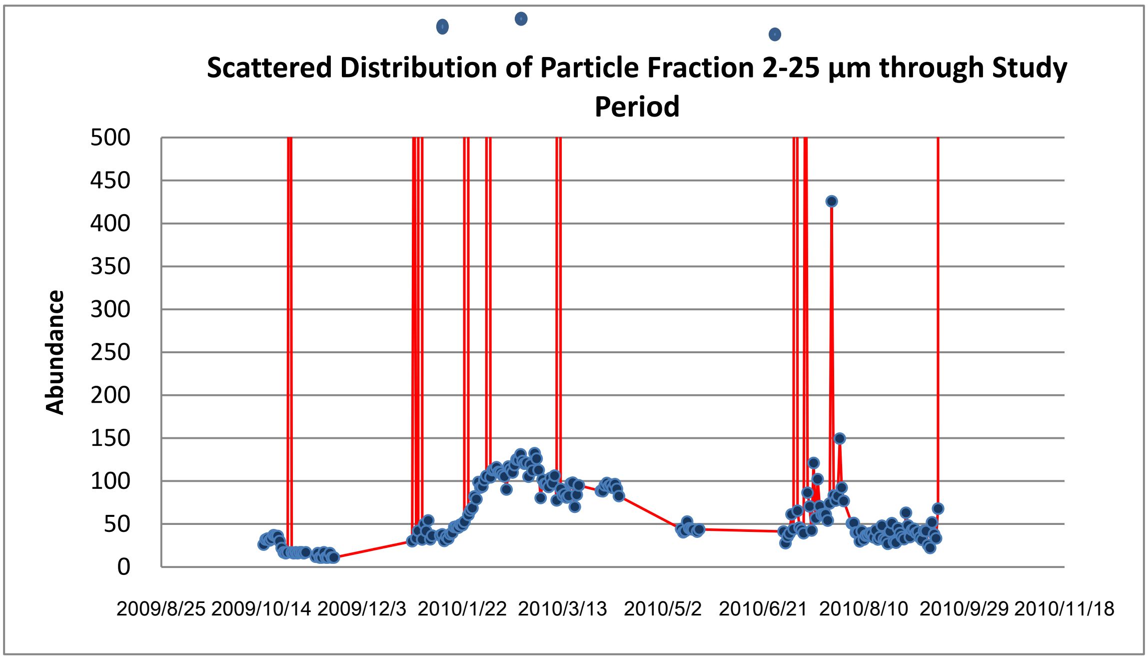


Figure 32. Scattered distribution of particle fraction 2-25 µm in drinking water, Borensberg Waterworks

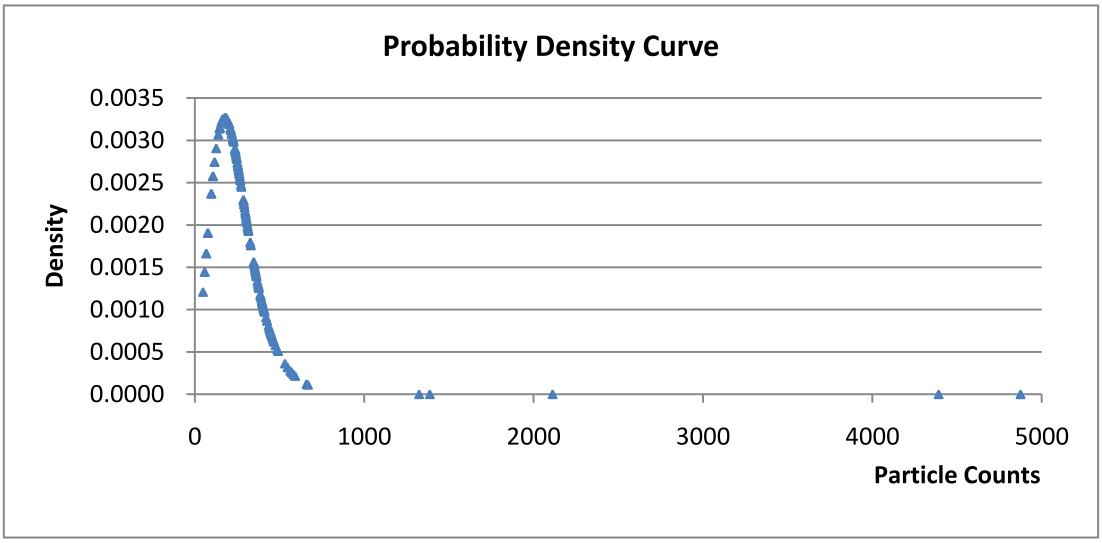


Figure 33. Gumbel probability distribution of particle fraction 1-25 μm in drinking water, Borensberg Waterworks.

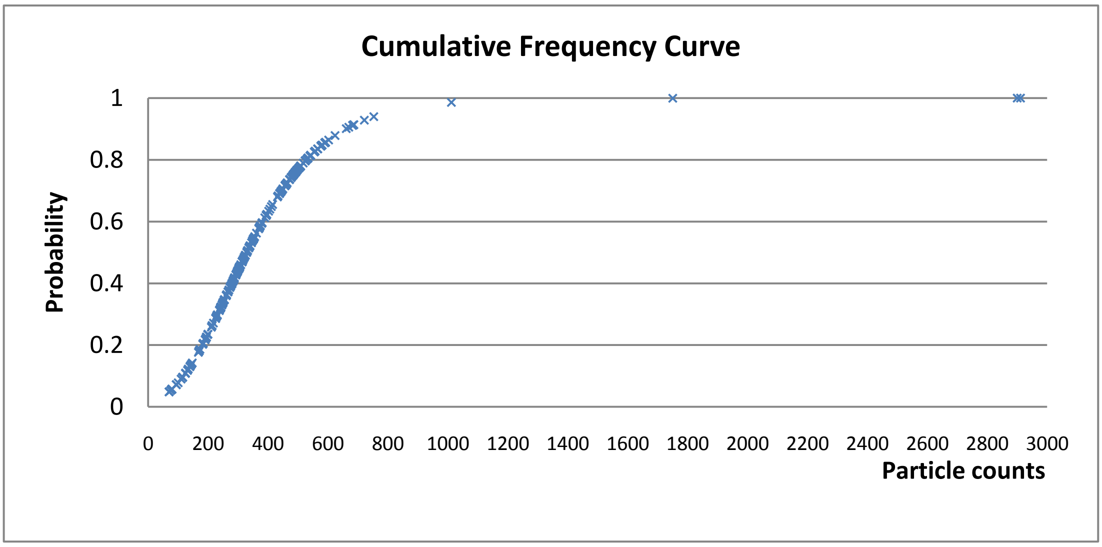


Figure 34. Cumulative Frequency Curve of particle fraction 1-25 μm in drinking water, Borensberg Waterworks

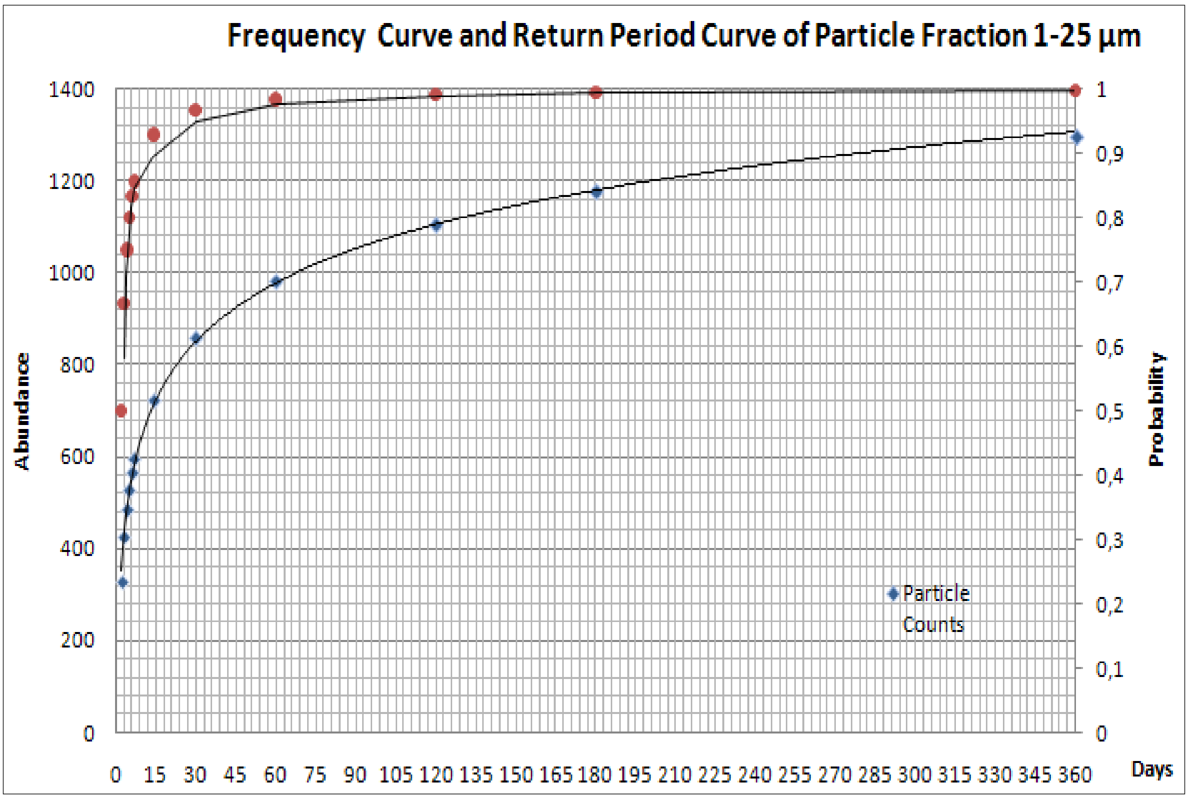


Figure 35. Frequency Curve and Return Period Curve for Particle threshold value definition of Fraction 1-25 µm in drinking water, Borensberg Waterworks.

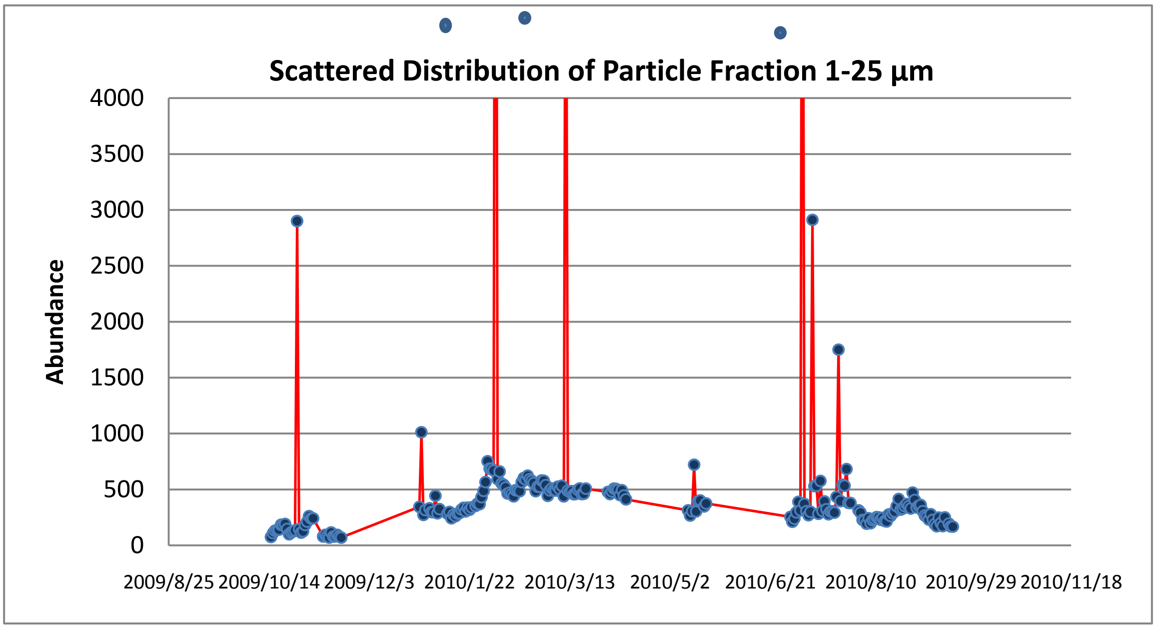


Figure 36. Scattered distribution of particle fraction 1-25 µm in drinking water, Borensberg Waterworks

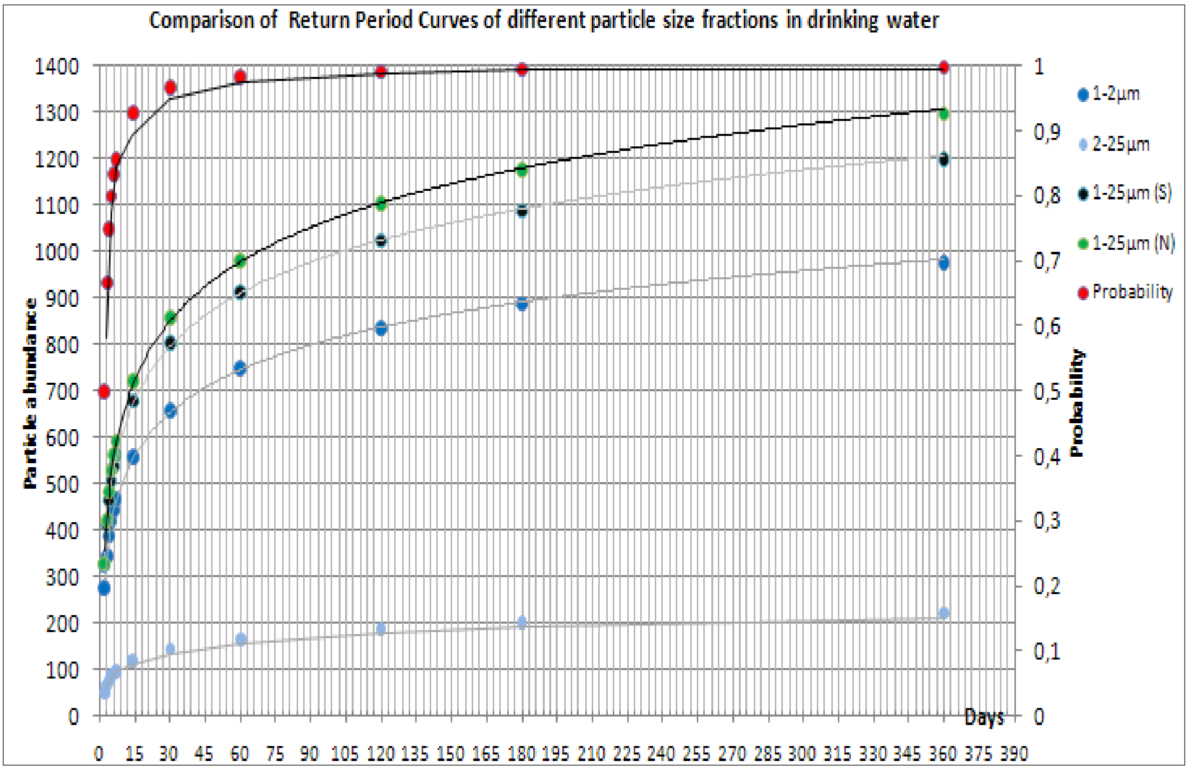


Figure 37. Comparison of Return Period Curve of different particle size fractions in drinking water. (Where the green dots represent the particle number calculated through numerical method and the dark blue ones are the summery of the smaller particle size fractions.)

Fig.37 shows the result of the return period and their probability for both two particle size fractions1-2 µm and 2-25 µm and summery of them. It also shows that there is a deviation of the frequency curve of the summarized counts from numerically derived one.

6 Conclusion

The most important findings are summarized and presented below:

1) The system could be used as an early warning system against contaminants with respect to microbial particle counts and inform the operator through message. It is perfectly possible to follow the particle fluctuations in real time for all fractions within 1-25 microns. Alarms and sampling can be done automatically with the P-300 system. Sampling can be done in the near sterile environment (but not entirely) for sample volumes up to 500 ml.

2) Correlation of particle population between raw water and drinking water is possible. Results show that there is no linear relation exists between total particles counts in raw water and drinking water. However, for micro particle size factions, the correlation between different fraction sizes both in raw water

and drinking water has varies through the study period. It shows apparent good correlation between almost all fractions in Dec.2009, Mar. and Jun. 2010. More and detailed investigation is suggested.

3) There is a weak positive link between the number of microbial particles in drinking water and microbiological contaminants in raw water, which is not statistically significant.

4) The correct choice of the threshold/alarm limit when automatic sampling is done can be made after a break-in period for the current water supply, but this value can be changed depending on aimed practical site and local conditions.

5) It is possible to reduce particle levels in drinking water by optimizing the operation.

6) The average Log Reduction value in Borensberg Waterworks' water supply is 1.05. The reduction is highest when the number of particles is highest in the raw water. It means that there is an improvement of the treatment within the water plant.

7) Particle Counters are sensitive to clogging of coarse material. Some form of efficient pre-filtering can be implemented to provide a safe working environment.

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RION'S Website: http://www.rion.co.jp/english/

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Table 5. Data Analysis on Particle Concentration in Four Seasons in Raw Water, Boren Lake (The Min., Max., Average and normal distribution range. (*Aver. Is the mean value of particle concentration; Min. and Max. are the minimum and maximum value of the particle concentration separately; Nor. U and Nor. L are respectively the upper limit value and lower limit value of particle normal distribution, σ is the standard derivation, R^2 is the correlation coefficient*).

Time	Autumn (Nov.2009)		Winter (2009-2010)		Spring (2010)		Summer (22/6-1/7,2010)		Summer (22/7-1/8,2010)	
Size	1-2 μm	2-25 μm	1-2 μm	2-25 μm	1-2 μm	2-25 μm	1-2 μm	2-25 μm	1-2 μm	2-25 μm
Aver.	1916	1215	3131	1701	2152	980	8121	5524	170590	194
Min.	1298	694	811	283	1535	635	1017	104	20240	7
Max.	2964	2141	9990	10000	9990	10000	17080	14400	412500	16245
Nor. U (95%)	2446	1717	5989	3343	3427	2010	11381	8490	224980	644
Nor. L (95%)	1387	712	145	-9,5178	908	-48	6200	3369	116210	-258
σ	264	251	1460	838	629	514	1295	1280	27190	226
R^2	0.95		0.99		0.94		0.97		0.56	

Table 8. Pearson Correlation Matrix between Raw Water and Drinking Water Varies in Different Months.

200911	1-2 μm	2-7 μm	7-15 μm	15-25 μm	2-25 μm	*SUM DR.*	1-2 μm R	2-25 μm R	SUM RAW
1-2 μm	1								
2-7 μm	0.95	1							
7-15 μm	0.99	0.98	1						
15-25 μm	N	N	N	1					
2-25 μm	0.95	1	0.99	N	1				
SUM DR.	1	0.96	1	N	0.96	1			
1-2 μm R	0.47	0.18	0.35	N	0.19	0.44	1		
2-25 μm R	0.55	0.27	0.44	N	0.29	0.52	1.00	1	
SUM RAW	0.50	0.22	0.39	N	0.24	0.48	1.00	1.00	1

200912	1-2 µm	2-7 µm	7-15 µm	15-25 µm	2-25 µm	SUM DR.	1-2 µm R	2-25 µm R	SUM RAW
1-2 µm	1								
2-7 µm	0.96	1							
7-15 µm	0.99	0.93	1						
15-25 µm	-0.21	0.06	-0.33	1					
2-25 µm	0.99	0.99	0.97	-0.08	1				
SUM DR.	1.00	0.97	0.99	-0.20	0.99	1			
1-2 µm R	0.88	0.73	0.93	-0.64	0.81	0.88	1		
2-25 µm R	0.89	0.73	0.94	-0.64	0.81	0.88	1.00	1	
SUM RAW	0.88	0.73	0.93	-0.64	0.81	0.88	1.00	1.00	1
010101-010107	1-2 µm	2-7 µm	7-15 µm	15-25 µm	2-25 µm	SUM DR.	1-2 µm R	2-25 µm R	SUM RAW
1-2 µm	1								
2-7 µm	-0.46	1							
7-15 µm	0.69	-0.26	1						
15-25 µm	0.65	-0.58	0.85	1					
2-25 µm	-0.46	1.00	-0.26	-0.58	1				
SUM DR.	-0.36	0.99	-0.18	-0.52	0.99	1			
1-2 µm R	-0.35	0.52	0.27	-0.10	0.52	0.50	1		
2-25 µm R	-0.38	0.57	0.25	-0.13	0.57	0.55	0.99	1	
SUM RAW	-0.36	0.54	0.26	-0.11	0.54	0.52	1.00	1.00	1
010111-010118	1-2 µm	2-7 µm	7-15 µm	15-25 µm	2-25 µm	SUM DR.	1-2 µm R	2-25 µm R	SUM RAW
1-2 µm	1								
2-7 µm	0.90	1							
7-15 µm	0.10	-0.21	1						
15-25 µm	-0.31	-0.50	0.14	1					

2-25 µm	0.91	1.00	-0.19	-0.50	1				
SUM DR.	0.99	0.94	0.03	-0.36	0.94	1			
1-2 µm R	-0.42	-0.60	0.54	0.03	-0.59	-0.47	1		
2-25 µm R	-0.35	-0.55	0.63	0.12	-0.54	-0.40	0.98	1	
SUM RAW	-0.40	-0.59	0.57	0.06	-0.58	-0.45	1.00	0.99	1
010119-010126	1-2 µm	2-7 µm	7-15 µm	15-25 µm	2-25 µm	SUM DR.	1-2 µm R	2-25 µm R	SUM RAW
1-2 µm	1								
2-7 µm	0.80	1							
7-15 µm	0.68	0.48	1						
15-25 µm	-0.36	-0.12	0.05	1					
2-25 µm	-0.33	-0.08	0.07	1.00	1				
SUM DR.	-0.27	-0.03	0.12	1.00	1.00	1			
1-2 µm R	-0.43	-0.56	-0.48	-0.09	-0.11	-0.14	1		
2-25 µm R	-0.56	-0.60	-0.57	-0.05	-0.07	-0.12	0.98	1	
SUM RAW	-0.48	-0.58	-0.52	-0.08	-0.10	-0.13	1.00	0.99	1
201002	1-2 µm	2-7 µm	7-15 µm	15-25 µm	2-25 µm	SUM DR.	1-2 µm R	2-25 µm R	SUM RAW
1-2 µm	1								
2-7 µm	0.80	1							
7-15 µm	0.80	0.70	1						
15-25 µm	-0.57	-0.60	-0.69	1					
2-25 µm	0.81	1.00	0.71	-0.60	1				
SUM DR.	0.99	0.89	0.81	-0.60	0.90	1			
1-2 µm R	0.17	0.38	0.15	0.07	0.38	0.24	1		
2-25 µm R	0.23	0.22	-0.01	0.36	0.21	0.24	0.83	1	
SUM RAW	0.21	0.32	0.09	0.20	0.32	0.25	0.97	0.94	1

201003	1-2 µm	2-7 µm	7-15 µm	15-25 µm	2-25 µm	SUM DR.	1-2 µm R	2-25 µm R	SUM RAW
1-2 µm	1								
2-7 µm	0.85	1							
7-15 µm	0.55	0.19	1						
15-25 µm	0.19	-0.10	0.57	1					
2-25 µm	0.86	1.00	0.22	-0.08	1				
SUM DR.	0.99	0.91	0.48	0.13	0.92	1			
1-2 µm R	0.27	-0.01	0.55	0.59	0.01	0.21	1		
2-25 µm R	0.40	0.11	0.61	0.46	0.12	0.34	0.95	1	
SUM RAW	0.32	0.04	0.58	0.55	0.05	0.26	0.99	0.98	1
201007	1-2 µm	2-7 µm	7-15 µm	15-25 µm	2-25 µm	SUM DR.	1-2 µm R	2-25 µm R	SUM RAW
1-2 µm	1								
2-7 µm	0.81	1							
7-15 µm	0.52	0.85	1						
15-25 µm	0.74	0.91	0.79	1					
2-25 µm	0.81	1.00	0.86	0.91	1				
SUM DR.	1.00	0.86	0.59	0.78	0.86	1			
1-2 µm R	0.49	0.60	0.71	0.68	0.60	0.52	1		
2-25 µm R	0.50	0.74	0.81	0.85	0.74	0.55	0.90	1	
SUM RAW	0.49	0.60	0.71	0.68	0.61	0.52	1.00	0.90	1