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The Impact of Lake Water Quality on the Performance of Mature Artificial Recharge Ponds

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Abstract: Artificial groundwater recharge is commonly used for drinking water supply although the resulting water quality is highly dependent on the raw water quality, and in many cases, pre-treatment is required. Such pre-treatment improves the drinking water quality, although how and to what extent pre-treatment affects the subsequent pond infiltration process is still unknown. Here we evaluate the impact of two different pre-treatment methods of water from a eutrophic, temperate lake. An artificial recharge pond was divided into two parts, where one received raw water from a lake only filtered through a 500 µm pore size drum filter, while the other part received pre-treated lake water using chemical flocculation with polyaluminium chloride (PACl), combined with sand filtration (contact filtration). Changes in water quality were assessed at different stages in the two treatment processes. We show that contact filtration reduced phosphorus with 96 %. Moreover, the total organic carbon (TOC) reduction was improved from 55 % to 70 %, corresponding to an average reduction from 3.5 mg/L to 2.4 mg/L In addition, the pre- treatment in the artificial recharge pond reduced the cyanobacteria blooms and reduced the microcystin level. However, there were no sigificant differences in microcystin levels in the groundwater, i.e. the artifical recharge infiltration pond was effective for microcystin removal even without contact filtration. Hence, in a broader drinking water management perspective, the presented method is promising to reduce the levels of cyanobacterial toxins, as well as nutrients and TOC, which are all predicted to increase in a future climate change perspective.

Keyword: Pre-treatment, Contact filtration, artificial recharge ponds, Infiltration ponds, Nutrients removal, Cyanobacteria, Groundwater, Microcystin, Eutrophic lakes, TOC

1. Introduction

Artificial groundwater recharge plays an essential role in the sustainable management of groundwater resources as the demand for high quality drinking water continuously increases with growing populations combined with overexploiting of groundwater resources [1]. Using artificial recharge of surface water for drinking water supply is commonly used in Sweden and elsewhere, such as in the Netherlands, Australia, China and US [2] [3][4] [5] [6]. In the Swedish context, about 100 treatment plants, representing about 25 % of the Swedish municipal drinking water supply in volume, apply artificial recharge [7]. A standard way of artificial groundwater recharge is to divert raw water, such as lake water, directly into artificial recharge ponds where the water slowly infiltrates and becomes groundwater. The water treatment plant then withdraws groundwater through wells and distributes it to consumers following disinfection and post-treatment, such as filtration or adjustments in hardness and pH. The water quality after the artificial infiltration is important for drinking water safety and is highly dependent on the raw water quality. Hägg et. al. 2018 showed that the final drinking water quality might follow the same pattern as the raw water quality in conditions without pre-treatment, according to experiences from 16 artificial groundwater treatment plants in Sweden [8]. Therefore, pre-treatment is often required before the water enters the artificial recharge ponds and it generally, improves the following treatment processes, as well as the final drinking water quality. However, to what extent this will influence the water quality evolution in the ponds and the final infiltrated water quality is still largely

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unknown.

Understanding of subsurface water quality changes is necessary when evaluating the suitability of the raw water quality and when deciding whether any pre- or post-treatments are necessary, as well as for assessing any potential impacts on other groundwater users [9]. The removal of natural organic matter from lake water is of considerable importance, as it may affect the drinking water quality in various ways [10]. Besides, cyanobacterial blooms in freshwaters have become a worldwide problem for both ecosystem function and human health [11]. Hence, to protect and safe-guard surface water supplies, such as lakes and rivers, has become challenging for society [11]. Eutrophic conditions tend to enhance the growth and bloom formation of algae, specifically cyanobacteria [12]. Moreover, rivers and lakes in boreal regions or those surrounded by large agricultural areas tend to trigger algal blooms [13] [14]. Previous studies have demonstrated the importance of reducing cyanobacteria and cyanotoxin levels in drinking water supplies, especially by keeping low nutrient levels, such as the total phosphorus (TP) below 20 μg/L, thereby reducing the probability of cyanobacterial blooms and high algal toxin levels [15]. For example, groundwater contamination by microcystin from toxic cyanobacteria blooms was observed in Lake Chaohu, China, which posed a significant health risk for residents when used for drinking water. To improve the raw water quality in such lakes is therefore of great importance not only when using surface water reservoirs, but also when producing drinking water from groundwater [16]. Moreover, examining the occurrence of microcystin in raw water sources and treated drinking water of Finnish waterworks showed that efforts should be made to stabilize the operational conditions of the artificial recharge to meet the high and rapid variations in the raw water source [17].

Since presence of cyanobacteria in drinking water may cause bad smell and taste or even health problems, a removal is necessary prior distribution. Removal of cyanobacteria and cyanotoxins by using bank filtration (sand filtration) at Lagoa do Peri, Brazil showed that the algal biomass removal mainly occurred in the upper 2 cm and no cyanotoxins were found in the monitored well water [18]. Others have also shown that chemical flocculation and filtration treatments are effective in removing cyanobacteria and harmful other compounds [19][20]. Furthermore, Svrcek and Smith (2004) thoroughly reviewed the efficiency of different treatment processes for the removal of cyanotoxins from potable water [21]. To remove intact algal cells, treatment process with more than 99.5 % treatment efficiency are, for example, coagulation followed by sedimentation; dissolved air flotation followed by rapid sand filtration; and lime precipitation followed by sedimentation and rapid sand filtration. Microfiltration/Ultrafiltration can remove more than 98% of the cells [21].

Here, we aim to assess how raw water quality variations influence artificial recharge performance and water quality in the following processes. Hence, several water quality indicators, such as organic matter, nutrients, cyanobacteria and their toxins were analysed and evaluated. Our study also aims at supporting decision-making at waterworks to identify proper pre-treatment methods/barriers for safe drinking water supply and to meet future challenges accompanying e.g. climate warming. Our study also contributes to further understanding of the challenges of cyanobacteria and their toxins in drinking water systems and decision support for monitoring and effective management of cyanobacterial issues in practice.

2.1 Case study description

The study was performed at the Vomb Waterworks, an artificial groundwater treatment plant in southern Sweden, which has been applying artificial recharge for more than 60 years. Vomb Waterworks is run by the largest drinking water supply company in south Sweden (Scania), Sydvatten, representing about 900 000 inhabitants from 17 municipalities. Raw water with a flow rate around 1000 L/s is taken from the Lake Vomb which is situated about 3 km northeast of the treatment plant and water is pumped to a sieve station with 500 μm pore size, removing macroparticles and reeds. The water is then distributed into infiltration ponds around the waterworks. There is in total 54 ponds (covering a surface of 430 000 square meter) but only half of them are in use at the same time. The water seeps slowly, with an average velocity of 0.4 m/d through the fine sand (grain size is about 0.5-0.8mm). It then takes about 2 to 3 months for the water to reach the 120 groundwater wells. The water is led to a drinking water treatment plant where the main process is to remove iron, reduce the hardness, adjust pH and disinfect the water before distribution to consumers [2].

The catchment area of the lake is 450 km^2 and with an average precipitation of 750 mm/year the renewable water resource is about 5 m^3/s. This catchment area has been used since 1948 for drinking water production due to the unique natural features. The southern area of the lake bottom is mostly composed of sand, pebbles and gravel that contain large amounts of groundwater. Therefore, the geological characteristics are well adapted for artificial groundwater recharge techniques [22]. However, Lake Vomb experiences cyanobacterial blooms almost every summer. A past observation of trace amounts of cyanotoxins in groundwater samples have prompted operators to improve the treatment process by introducing pre-treatment. In this study, one of the fifty artificial recharge ponds at Vomb Waterworks was used. The pond was divided into two parts, where one received untreated lake water, while the other received pre-treated water through chemical flocculation combined with dynamic sand filtration (contact filtration).

2. Material and Methods

2.1 Contact filtration

Contact filtration is using Upflow Solids Contact Filter which eliminates the need for separating flocculates and settling tanks, since liquid-solid separation, filtration, and sludge removal are done in a single unit process. Coagulation and flocculation are performed in a granular medium such as a constant motion in the sand bed. This purifies water and at the same time washes the sand without interruption and additional maintenance (for a detailed description of the technology, see [23]. The filters are commercially available. In our study, we applied Dynasand filters (Nordic Water, Gothenburg, Sweden). In brief, the process involves chemical precipitants (Polyaluminium Chloride) which are added to a mixer in the pipe system before it reaches the filters. Hydroxide flocks are formed and are then coagulated, filtered and separated directly inside the filter bed. This process is suitable for treatment of surface water and is commonly used in small scale water treatment plants (< 20,000 m3/year) in Sweden, for example, Kalmar, Karlskoga and Karlskrona [8].

2.2 Study design

The project design is illustrated in Fig.1. The artificial recharge pond was divided into two separate parts of similar size and shape, one receiving lake water after micro-sieve filter (500 μm) (control treatment) and one after contact filter (contact filter treatment). Both ponds were maintained in the same way and received the same water flow. To be able to follow the treatment process during the study, 4 observation wells were used for groundwater sampling. They are located 2 meters from the sides of each pond and were on average 13 meters deep (Fig. 1). The average depth of the groundwater table to the top is around 3 to 5 meters. For a seeping rate of 0.4 m/day, it was estimated that it might take less than a week to reach the closest observation wells. As the deviation of the pond with a deep wall in the middle and two water flows entered the pond from the side, the groundwater collected in the closest wells from both sides was assumed independent. The flow in the inlets of both halves were constant at 10.5 l/s. After 4 months, the standing water in the both half ponds were visibly different.

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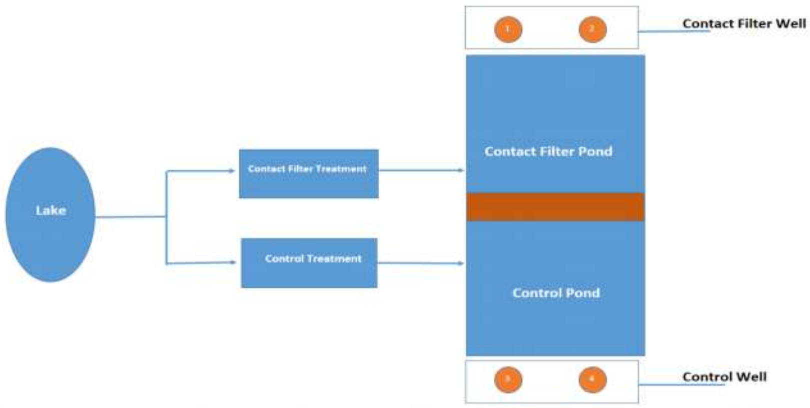

Figure 1. Overview of the study site. The Lake is Lake Vombsjön from which water was led either through contact filter treatment or control treatment and then enter different pond sides, contact filter pond and control pond.

2.3 Samplings

Samples were taken from 10th of June to 20th of October 2014 at several sites along the treatment process, including from the incoming lake water, pre-treated water after control treatment and contact filter treatment, water from the contact filter pond and control pond and infiltrated water from all four wells (Fig. 1). Sampling for the cyanobacterial toxin microcystin were taken from 10th June 2014 to April 2015. The number of samples for each parameter are summarized in Supplement 1 Table 1.

Water quality parameters that were sampled were: Turbidity (FAU), UVA_{254nm}, Color (436nm), chemical oxygen demand (mg COD/L), Total Phosphorus (mg/L), pH, total organic carbon (mg TOC/L), nitrate (mg/L), orthophosphate (mg/L), cyanobacteria and microcystin.

A Hach Patio/XR turbidimeter was used for turbidity measurements and a WTW 197-S pH meter for pH measurements. An DR6000™ UV VIS Spectrophotometer was used to measure: UVA254nm and water color. Colourimetric titration with Potassium permanganate was used for COD measurement. TOC samples were sent to specialized laboratory (Eurofins). Orthophosphate and total phosphorus were measured by HACH LANGE test kits at the above spectrophotometer. Algae analysis was done by microscope with maximal enlargement of 400x. The following taxonomic groups were distinguished:

-1: *Woronichinia/ Snowella / Mycrocystis / Radiocystis*
-2: *Chroococcus*
-3: *Beggiatoa*
-4: *Achroonema / Limnothrix / Planktolyngbya*
-5: *Anabaena / Nostoc*.

Beacon Microcystin Tube Kit were used for microcystin analysis. (Beacon Analytical Systems Inc., 2019). The evaluation of this method as a quick analysis for field tests has been demonstrated in previous work, where it showed 20 % false ''positive'' compared to analytical method HP-LC [15]. One of the reasons of the results being positive was due to cross-reactivity with other microcystin variants. The official detection level for the microcystin test is 0.3 µg/L [25]. According to the company, through spike and recovery experiment with standard solution, values below 0.3µg/L might also be valid. For discussing the difference of the impact on Microcystin evaluation by using different standard levels, it was assumed that all the data measured could be used for analysis.

The guideline value of microcystin monitoring in raw water and drinking water by the World Health Organization is 1µg/L [26]. However, there has been more cautious health concern initiatives, such as in 0.16 µg/L in Vermont and 0.1 µg/L in Minnesota in U.S.A. (Vermont Environmental Conservation, 2007) [28].

2.4 Bootstrapping resampling

Data resampling refers to methods for economically using a collected dataset to improve the estimate of the population parameter and help to quantify the uncertainty of the estimate. Bootstrapping is one of the resampling methods, which relies on random sampling with replacement. It allows assigning measures of accuracy, defined in terms of confidence intervals in this study for example, to sample estimates. This technique allows estimation of the sampling distribution of almost any statistic using random sampling methods [29].

3 Results and Discussions

Improving raw water quality by introducing pre-treatment has many advantages. Reducing dissolved organic matter and particles before infiltration, results in less clogging and maintenance of artificial recharge ponds. Water quality at different stages along the treatment process are presented in Supplementary Table 1. In the following sections, we analyse the water treatment performance according to the capacity of the two treatments in removing organic matter, nutrients and cyanobacteria and their toxins.

3.1 Organic matter and particles removal

One major priority for drinking water producers is to remove particulate materials, i.e. inorganic and organic particles. Particulate materials from the raw water and flocs formed during chemical flocculation are physically removed by filtration processes. This can be seen in S. Fig. 1, where contact filter treatment removes about 50 % of particles from the raw water measured as turbidity (FNU). Comparing these results with the control treatment, there is only a slight turbidity decrease. This difference comes from the drum filters ability to only remove particles larger than 500 μm, which is too large to remove algae and could partly explain the increased turbidity and large variances observed in the control pond (S. Fig. 1). While for the experiment pond water, the turbidity remained similar after chemical flocculation and contact filtration.

These results may have important impact on infiltration pond maintenance and treatment capacity. If it is possible to reduce organic and inorganic particles in the ponds, this would translate to higher infiltration capacity and less maintenance due to higher infiltration rates and less frequent cleaning of the ponds. However, the reduction in turbidity was not carried over to the wells, because of the infiltration fields' ability to remove particles from the raw water.

Fig. 2 shows the impact of contact filtration on the entire treatment process; the organic content in water from the contact filter process is significantly lower than in the control treatment process. After chemical flocculation and contact filter treatment, the TOC-content was reduced by around 50 %, which is similar to other flocculation studies with the same source water [30] and within the observed range of other WTP's in Sweden using contact filtration [8,31,32]. The final TOC-content in the wells was reduced from 3.5 mg/ L to 2.4 mg/ L when applying contact filtration, which translates to an overall TOC-reduction from 55 to 70 %. This is achieved partly by the two different technique´s abilities to remove different fractions of organic matter [33]. However, the TOC-reduction during infiltration (from control pond to control wells) was higher using none-treated raw water, which would suggest that infiltration and chemical flocculation also reduces similar fractions of organic matter.

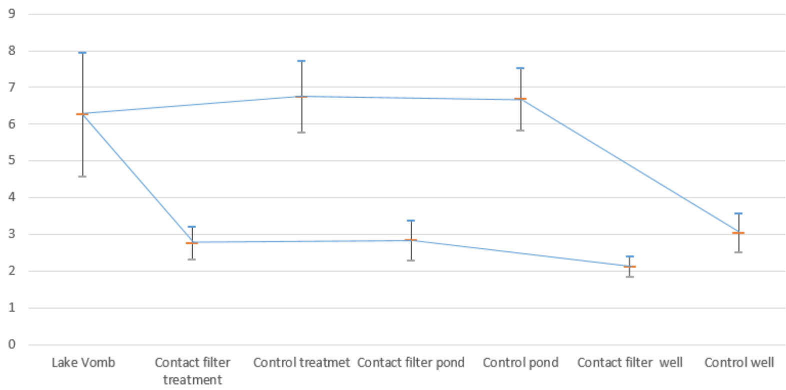

Figure 2. TOC measurements at different stages along the two treatment processes (mg/ L)

Similar trends were observed for other indicators of Natural Organic Matter content (NOM), i.e. chemical oxygen demand (COD) and UV-absorbance (UVA), where contact filtration reduced these parameters significantly before infiltration process (S. Fig. 2 and 3). The large variance of the COD and UVA measurement results in the wells however, makes it difficult to claim any difference in total removal rates for the two treatment processes. This could be because they do not directly measure organic matter. COD for instance, is influenced by naturally occurring iron and manganese, and UVA only captures organic matter, and any other matter, that absorbs UV-light.

3.2 Nutrients removal

Phosphorus removal using chemical coagulation and quick sand filtration has been proved to be very effective in previous studies [34], [35]. This is also verified by our study where up to 95% of the phosphorus was removed after contact filter treatment (Fig. 3). To keep a low concentration of phosphorus (< 20 μg/L) is crucial for cyanobacterial bloom control [15]. Contact filter treatment dramatically prevented intensive cyanobacterial blooms compared to the reference pond where the phosphorus remained the same as in the source water (Pic. 1).

Picture 1. Onsite observation of two sides of pond, left: control pond, right: contact filter pond

The general nitrogen condition was low and did not change along any of the treatment processes. This might also demonstrate that phosphorus control for cyanobacteria growth is more effective than nitrogen control.

The nitrate level in the final production from the conventional treatment side even showed increased values as it might be contributed by the decay of algae and nitrification process converting ammonia to nitrate (S. Fig. 4 and 5). This also might show that this infiltration layer is under anaerobic condition, maybe due to high TOC-load from cell growth in the pond.

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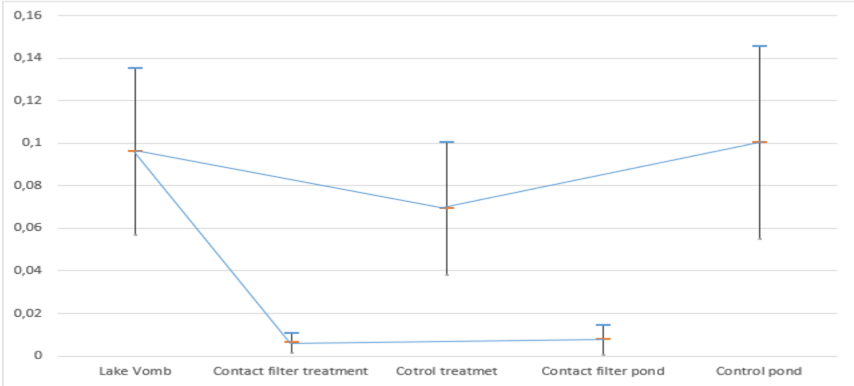

Figure 3. Phosphorus removal after contact filter treatment at different stages along the two treatment processes

3.3 Cyanobacteria removal

On site observation in Fig. 1 has already showed clear evidence of water quality improvement by introducing contact filtration. The cyanobacteria biomass in the control pond was about 8 times more than in the contact filter pond. The dominating species of cyanobacteria in the control pond are group 1 (*Woronichinia*/ *Snowella* / *Mycrocystis* / *Radiocystis*) followed by group 5 (*Anabaena* / *Nostoc*.) and group 2 (*Chroococcus*) (S. Fig. 6). Only group 1 (*Woronichinia*/ *Snowella* / *Mycrocystis* / *Radiocystis*) and 4 (*Achroonema* / *Limnothrix* / *Planktolyngbya*) were present in the contact filter pond (S. Fig. 6).

The difference of those groups are mainly their morphology and size. Some cyanobacteria species with smaller cell size passed the contact filter. The rest group with larger cell size and filaments might be filtered out or growth limited due to low phosphorus supply in the pond.

One way to control cyanobacteria biomass is to reduce the phosphorus concentration, such as discussed above. Another approach is to change the nitrogen to phosphorus ratio. Low nitrogen and high phosphorus support nitrogen fixing cyanobacterial blooms. Hence, a low nitrogen to phosphorus ratios (N:P < 15) will trigger nitrogen fixing species, such as *Woronichinia naegeliana* [36]. In our case the ratio between N:P on the contact filtration side was above 40, but less than 10 on the reference side. The nitrogen fixing species, such as *Anabaena* was absent in the pond after contact filtration while it thrived in the reference pond water. In a previous study we also discussed how low N:P ratios may trigger higher cyanobacterial blooms [37].

There were no traces of cyanobacteria in the well samples, suggesting that the infiltration process in the pond was able to remove cyanobacteria even when there were intensive blooms in the control pond water.

3.4 Cyanotoxins analysis

Microcystis and *Anabaena* (*Dolichospermum*) are listed as the most toxic cyanobacterial genera and often succeed each other during harmful algal blooms [38]. *Woronichinia naegeliana* appears frequently in freshwater and one study showed that blooms of *W. naegeliana* was toxic towards invertebrate zooplankton [39].

The microcystin are hepatotoxic products of freshwater cyanobacterial blooms of *Microcystis, Anabena* and *Nostoc* with *M. aeruginosa* being the most common [40][26]. *Anabaena* might also produce anatoxin and saxitoxins [26].

As mentioned in the methods section, all microcystin data were taken into concern for analysis. Boxplot results are illustrated in S. Fig. 7 showing that there is almost no difference between the median values of microcystin levels at different stages.

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Contact filter treatment was more efficient in microcystin removal compared to the drum filter, which had almost no effect on microcystin reduction (Fig. 4). After drum filter, microcystin was similar to the source water, where it was close to the guideline value of 1 μg/l and it might increase following the intensive cyanobacteria growth in the pond water.

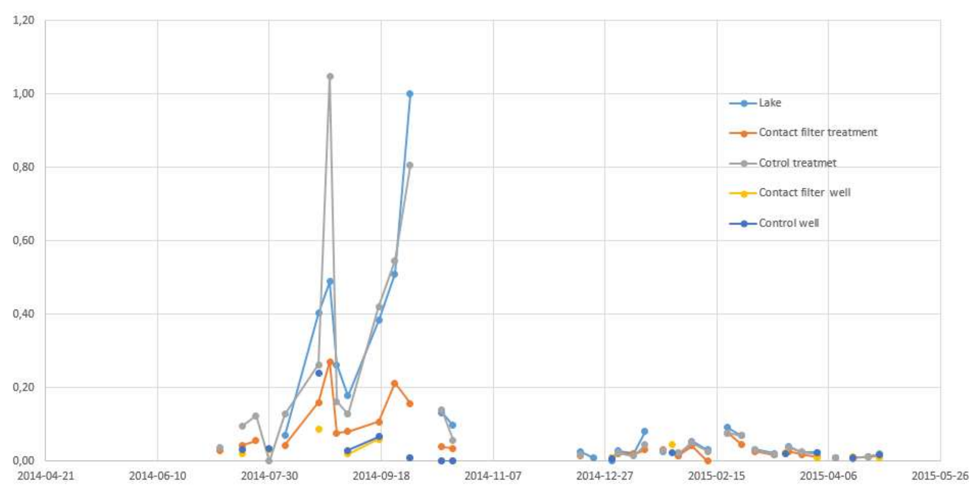

Figure 4. Microcystin development along the sampling period

Is the difference of significance between two types of pre-treatment? Bootstrapping was used for comparison of the difference in toxin concentrations in regards of their mean, variance and standard deviation and 1000 resampling iterations were generated. In every iteration, the mean difference between microcystin values after drum and contact filtration were calculated. The distribution of the mean difference was plotted as in the Fig. 5 where all possible difference that are close to the population difference is illustrated. About 98% of the mean differences were positive i.e. toxin level after drum filter is bigger than the one after the contact filter. The range of difference between 0.015-0.19 is under 95%, thus the confidence intervals indicate the difference is significant. The sample mean difference of toxin condition after reference treatment and new treatment which is 0.079 (the blue line), close to the median of the distribution suggests it has high possibility to happen. We can conclude that we have 98% confidence to say the difference between means of microcystin level after two types of treatment processes is significant. This same analysis was done for evaluating the difference of the variance and standard deviation.

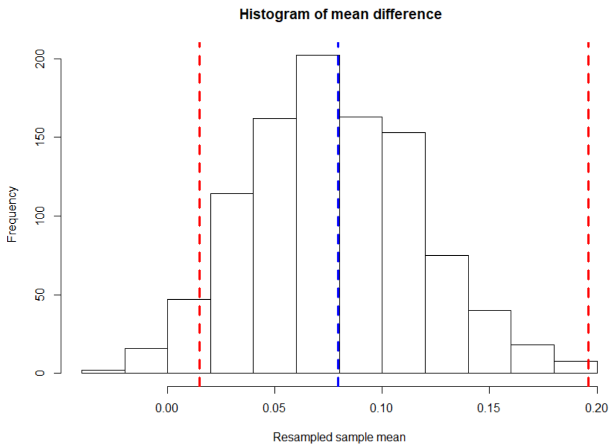

Figure 5. The distribution of mean difference of toxin level after reference treatment and new treatment

However, when it comes to the well water, there is no difference between the microcystin concentration in the control well and contact filtration well. We can conclude that under current

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microcystin level in raw water, the artificial recharge is effective to remove the microcystin even without introducing new treatment.

3.5 Discussion around microcystin detection, monitoring and treatment

Guideline values applied for microcystin condition will influence the management strategies. The current guideline for microcystin monitoring used in Sweden is the WHO guideline of 1 µg/L, and our lake water and conventional treatment process might rise above this level. The infiltration ponds seem to work well for removing microcystins as the level in the final water is far lower than 1 µg/L.

It might be another story, if authorities decide to lower the accepted microcystin levels. For example, water facilities in Minnesota and Vermont were not allowed to have microcystin LR values above 0.1 µg/l and Vermont 0.61 µg/l, respectively. Even though the USEPA does not require testing for cyanotoxins, Vermont has a strong network of voluntary sampling and recommends that water supplier initiate targeted monitoring. It also became a policy of the Drinking Water and Groundwater Protection Division (DWGWPD) to encourage source water monitoring by public surface water systems, and to facilitate appropriate public notification and operational actions if cyanotoxins are detected in finished water at concentrations at or above health advisory levels (0.1 µg/L) established by Department of Health [28].

In this case, the contact filtration demonstrates its advantage by reducing the risk of microcystin during the pre-treatment process with 13% above 0.1 µg/l instead of 30% by conventional way. In addition, the end water sent for consumption was kept below 0.1 µg/l.

3 Conclusion

We have here demonstrated how and to what extent pre-treatment of raw water affect the water quality through two treatment processes and their influence on the final water production. The key conclusions are summarized below:

By installing contact filtation we can improve the raw water quality supplied to the infilration pond considerably, especially regarding TOC-reduction (on average by 70%) , COD-reduction (on average by 73%), UVA_{254nm} measurement reduced on average 74% and TP-reduction (on average by 95%). This leads to a reduction of the total TOC-concentration in the final product from around 3.5 µg/L to 2.4 µg/L and COD-reduction from around 2.1 µg/L to 1. 5 µg/L. At the same time, it deceased intensive cyanobacteria blooms in the artificial recharge ponds. Only small cell cyanobacteria passed the contact filter, which, however, were limited to grow due to lack of phosphorus. While in the control pond, toxic species were dominating and forming more frequent blooms.

What pre-treating raw water contributes to is reduction of organic load in the infiltration ponds as well as groundwater of higher quality. The contact filter treatment spells to less infiltration pond maintenance and higher infiltration capacity, which could be very impactful for artificial groundwater recharge plants with less usable infiltration area.

Under current microcystin levels in raw water, the artificial recharge is effective to remove the microcystin even without introducing new treatments although microcystin risk might increase in the artificial recharge pond. For cyanotoxin monitoring, detection and treatment, there is still a lot of work to do. We might face stricter alert values in the future due to strict health concerns or political initiatives that might challenge existing monitoring programs and require more stringent treatment of toxins in water. If so, the evaluation programs of toxin conditions need development of more accurate detection methods with sufficienct detection level.

Different options of toxin treatment needs to be tested with higher toxin levels which is likely to happen in the future with warmer climate induced cyanoabacterial growth followed by increased cyanotoxin levels in raw water. The cyanobacteria microflora is a complex system with many toxic species producing various toxins. The cyanotoxin monitoring needs to cover at least anatoxins and possibly saxitoxin besides microcystin, as they might be produced by the species presented.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are not publicly available due to request from Sydvatten, but are available from the corresponding author on reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

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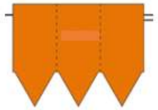
Supplementary Table 1. Water quality at different stages along the treatment processes

Treatment train	Raw			Pretreatment					Artificial recharge Pond					Well water				
				After contact filter treatment		After control treatment			Contact filter pond		Control treatment pond							
Water quality														Contact Filter Well		Control Filter Well		
	Avergae	Min-Max	No.	Avergae	Min-Max	Avergae	Min-Max	No.	Avergae	Min-Max	Avergae	Min-Max	No.	Avergae	Min-Max	Avergae	Min-Max	No.
TOC	6.25	4.3-9.1	n=6	2.75	2-3.3	6.7375	5.5-8.5	n=8	2.82	2.1-3.2	6.67	5.1-7.4	n=6	2.1	1.9-2.5	3.01	2.1-3.5	n=7
COD	4.955	4.13-5.64	n=10	1.70	1.42-2.36	4.76	4.03-5.51	n=14	1.71	1.27-2.42	5.333	4.27-6.37	n=8	1.26	1-1.55	1.55	0.67-12.28	n=8
Turbidity	4.59	(2.4-6.5)	n=9	1.01	0.3-5.82	3.76	2.7-4.5	n=9	1.3	0.25-5.75	4.64	(3-14.2)	n=9					
UV (A254 nm)	17.19	(15.9-17.7)	n=9	5.51	4.53-7.15	16.44	15.1-17.1	n= 13	5.18	4.7-5.75	16.33	(15.1-16.4)	n=8	4.42	1.14-6.93	5.16	1.22-7.24	n=9
Colour	2.09	1.56-2.18	n=9	0.33	0.24-0.63	1.46	1.01-1.94	n= 13	0.51	0.211-0.593	1.56	1.14-1.72	n=8	0.87	0.24-1.32	0.38	0.04-1.41	n=8
TP	0.096	0.041-0.194	n=11	<0.02	<0.02	0.0694	0.02-0.106	n= 15	<0.02	0-0.018	0.100	0.06-0.216	n=9	<0.02	<0.02	<0.02	<0.02	n=9
Ammonium	0.069	0.014-0.234	n=9	0.057	0.024-0.1896	0.052	0.018-0.164	n= 13	0.044	0.011-0.096	0.049	0.03-0.099	n=6	0.0082	0-0.021	0.0075	0-0.02	n=5
Nitrate	0.3687	0.203-0.989	n=10	0.516	0.035-1.6	0.559	0.207-1.66	n=15	0.392	0.206-1.08	0.318	0.143-1.02	n=6	0.55125	0.149-1.63	0.833	0.277-1.56	n=8
Orthphosphate	0.1685	0.049-1.02	n=10	<0.02	<0.02	0.0694	0.02-0.106	n=15	<0.02	0-0.019	0.100	0.06-0.216	n=9	0.0488	<0.02	<0.02	<0.02	n=8
Cyanobacteria	Present			NO		present			NO		present a lot							
Microcystin	0.138	0-1	n=30	0.053 n=33	0.01-0.27	0.132 n=34	0.01-1.05		0.0548	0.01-0.30	0.138	0.01-0.75	n=30	0.026	0-0.09	0.029	0-0.24	n=19

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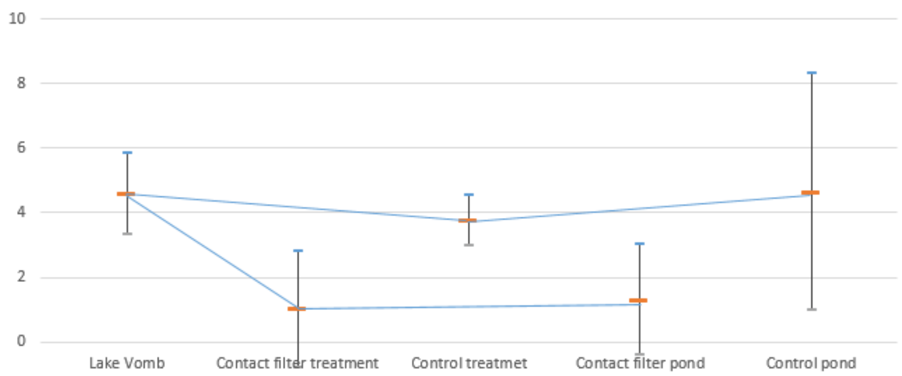
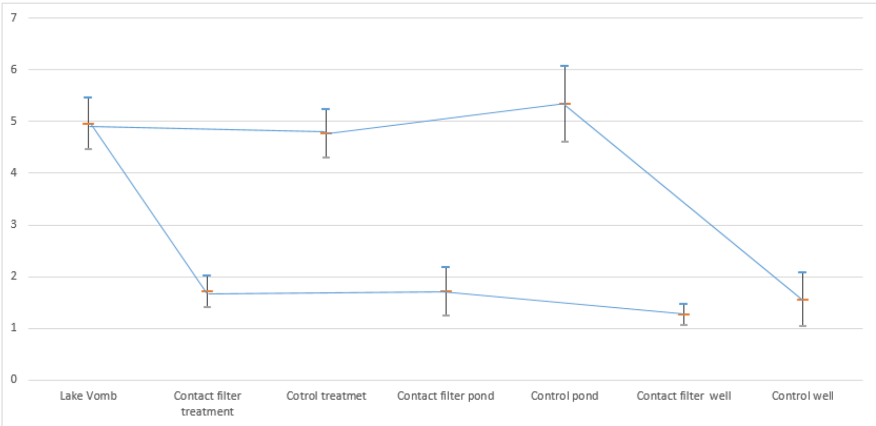
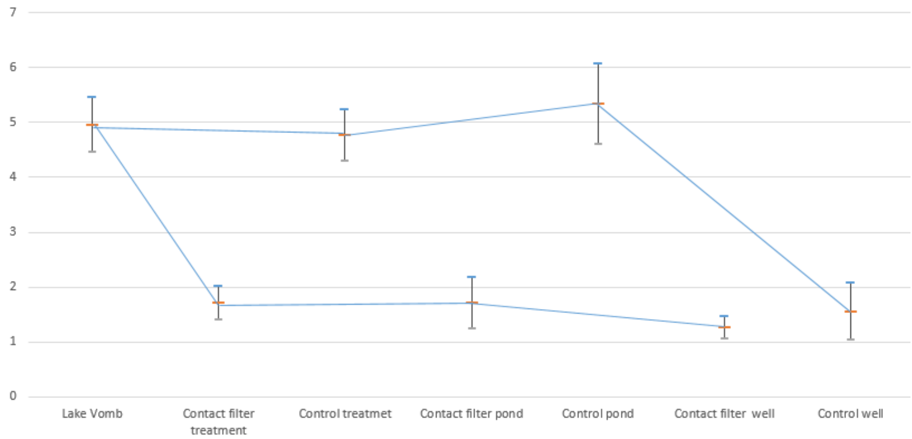


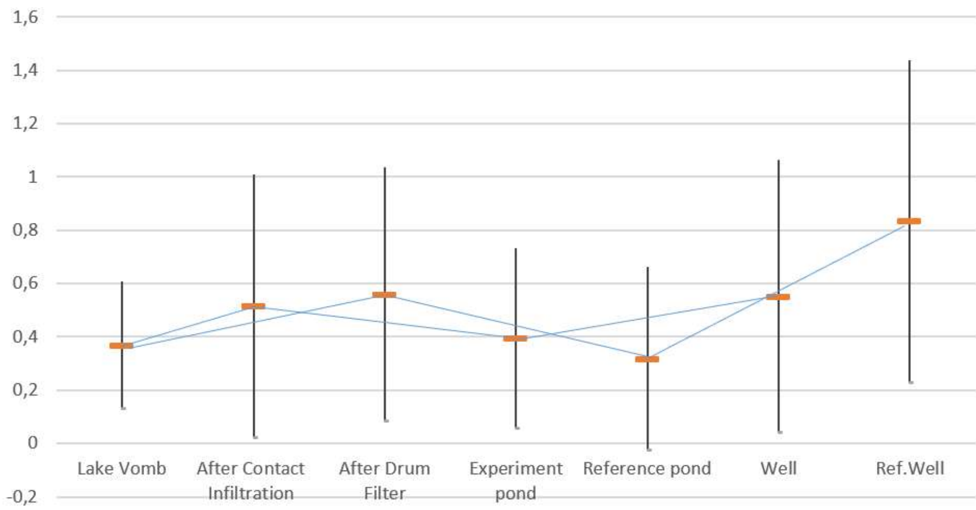
Supplementary Figure 1. Turbidity measurements at different stages along the two treatment processes (FAU)



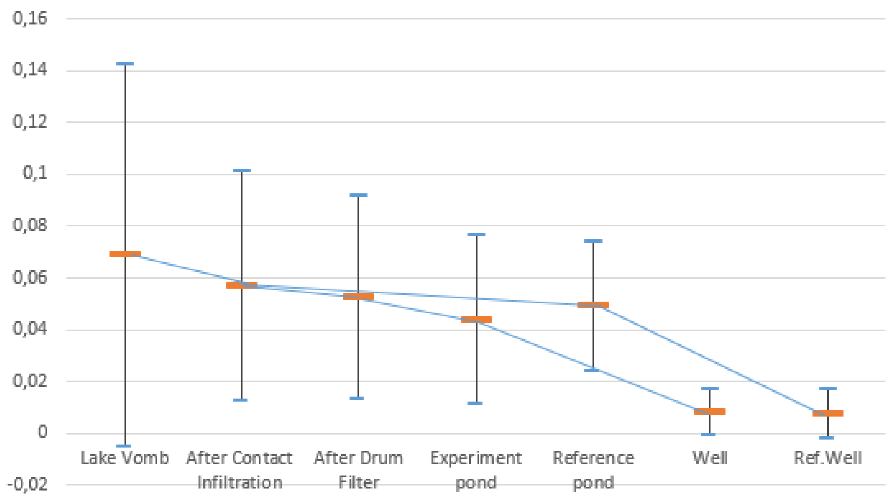
Supplementary Figure 2. COD measurements at different stages along the two treatment processes (mg/l)



Supplementary Figure 3. UVA 254 nm at different stages along the two treatment processes



Supplementary Figure 4. Nitrate content at different stages along the two treatment processes (mg/l)



Supplementary Figure 5. Ammonium content at different stages along the two treatment processes (mg/l)

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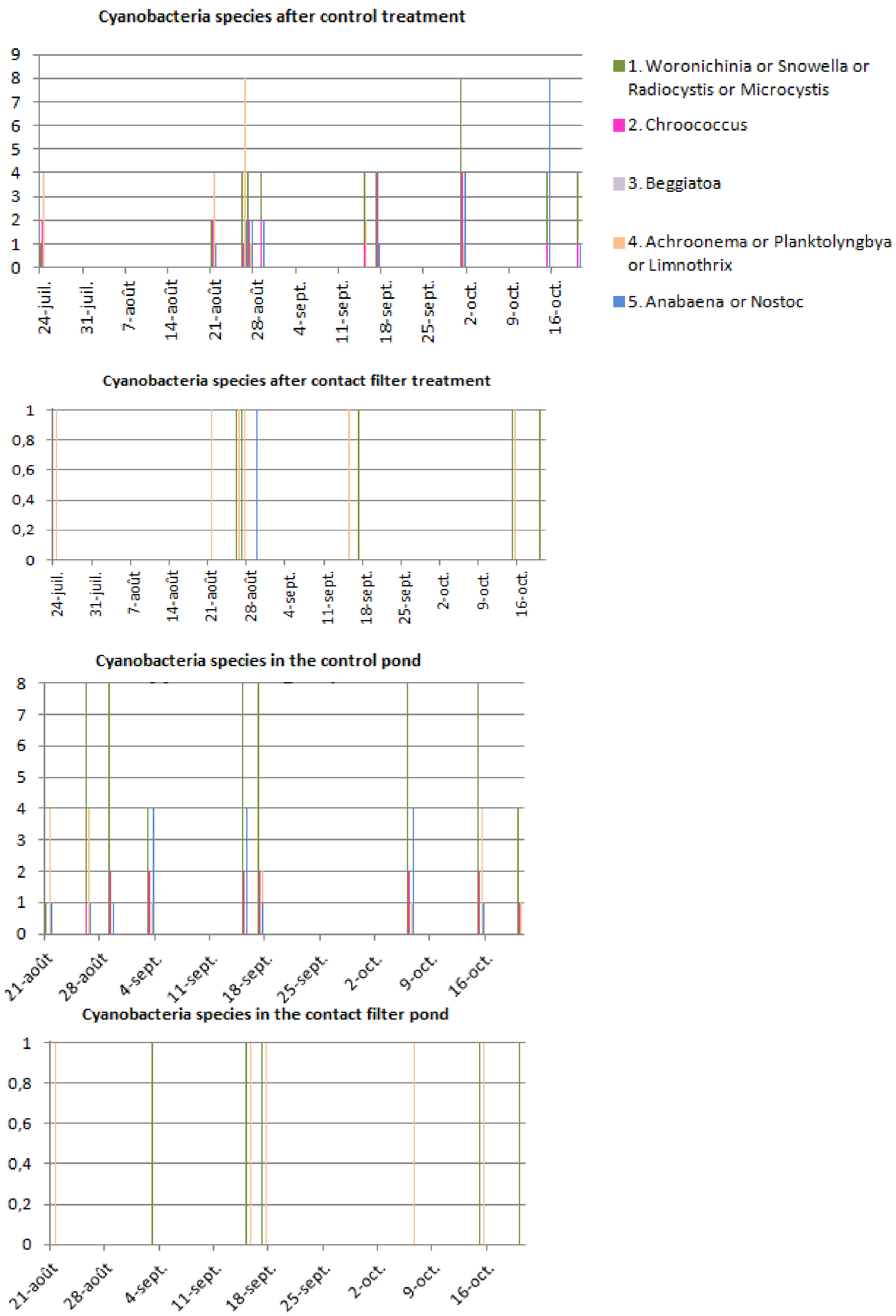
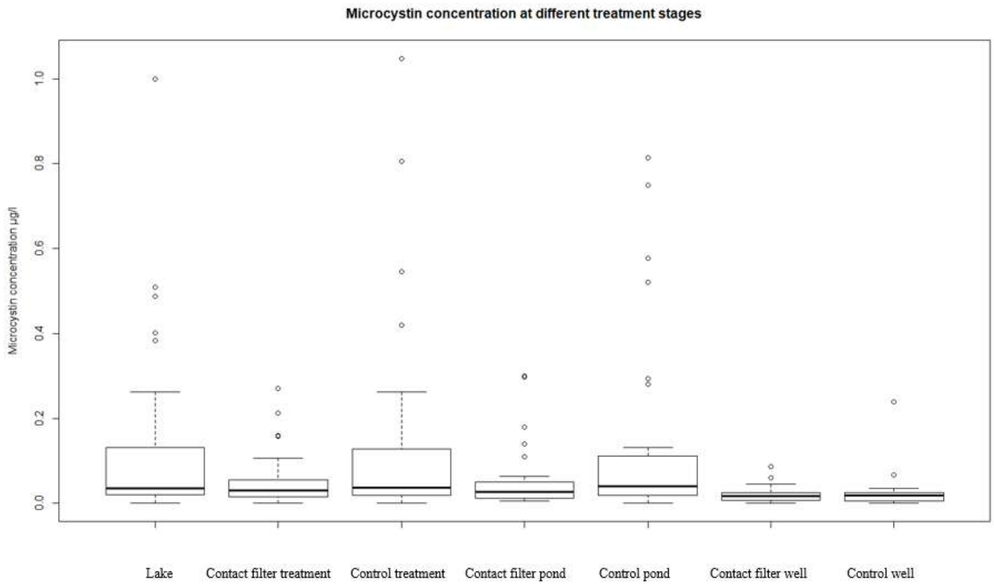


Supplementary Figure 6. Changes of algae types in the two treatment processes



Supplementary Figure 7. Microcystin concentration at different treatment processes