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The Evaluation of the Rapid Sand Filter Wash Interval at the Central DWTP in the Czech Republic †

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Abstract: This paper evaluates the washing interval of the rapid sand filter at the central drinking water treatment plant Nová Ves—Frýdlant nad Ostravicí in the Czech Republic (DWTP Nová Ves). The aim was to conduct automated flow cytometry measurements (FCM) and find the link between FCM and turbidity. The monitor parameters were the length of the wash cycle in hours, the flow rate of the filter and the production, the pumping of the recirculating wash water, and the physico-chemical and microbial analysis of the water samples. The focus of this paper is the detailed characteristics of the filtration mode evaluated during the summer and winter periods. During the measurements, it was confirmed that turbidity replicated the FCM data measured by the FC BactoSense instrument. Turbidity can be identified as one of the key features that can be related to the measurements made. Turbidity and the cell count itself are influenced, among other things, by the pumping of the return water, whereby an increase in the cell count can be observed after the pumping has stopped but gradually stabilizes at the values measured before pumping.

Keywords: rapid sand filter (RSF); drinking water treatment plant (DWTP); flow cytometry (FCM); turbidity; filter washing; conventional water treatment; drinking water

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1. Introduction

The purpose of drinking water treatment plants (DWTPs) is to provide safe water of good sanitary and chemical quality to the public [1,2]. The key processes used in drinking water treatment plants to remove dissolved and solid contaminants from source water include coagulation/flocculation, sedimentation, oxidation, and filtration systems [3]. Membrane filtration and granular bed filtration are used as filtration systems. Depending on the origin of raw water, different configurations are used to remove microbiological or chemical pollutants. Surface water usually requires multiple treatment steps [1] compared to groundwater, which often requires simpler treatment. The final step is then the sanitation. The quality of drinking water is determined by the legislation and also ensures the protection of the water supply (distribution) system, especially against corrosion and fouling.

Current climate change may be a major challenge for water supplies, especially in countries such as the Czech Republic, where all rivers originate, and surface water quality may be unstable [4,5].

With regard to the development and optimization of filtration technologies, it should be noted that water filtration is still a very conservative area and that some important advances are being made. These developments, although based on basic concepts, make the entire process more efficient and have a positive impact on the economy. The concept has remained unchanged for decades, but only variations developed and adapted to different conditions, such as different raw water quality and conceptual changes in process lines, allowing for the processes to be optimized according to different requirements [6–9].

The theoretically permitted filter cycle time considers the possible growth of organic matter in the filter bed. For each filter, the theoretical filtration cycle length should be determined. High-quality raw water filters can achieve a seven-day filtering time. However, it should be considered that a relatively long time period may result in an increase in organic and microorganic matter in the filter bed and may lead to staleness of the filter bed. The unwanted result is both the smell and taste of the filtered water, as well as the formation of slime compounds that affect the difficulty of filter washing. For this reason, the operation is usually guaranteed by shorter filtration cycles, higher filter washing frequency, and higher washing water intake associated with this process [6]. In particle tracking methods, it was shown that turbidity measurements themselves are insufficient to properly map the filter process. The measurement of the number of particles is about 20 to 25 times more sensitive than measuring the residual turbidity of treated water [10]. Therefore, new methods are proposed, such as particle counters and flow cytometers (FCMs) [11,12], which may be used to monitor water filtration processes more accurately.

FCM is a method that has become increasingly popular in water management practices in developed countries [12–14]. It is used to accurately quantify the total microbial recovery in water, not only the total number of cells per mL, but also classifying cells into small, large, alive, and dead cells (using simultaneous light scattering and fluorescence measurements combined with dye stains for counting and analyzing). This also gives a clear graphical representation of the cell distribution (the so-called "fingerprint"). In addition to laboratory FCM, there is now a complete automation online FCM that can be easily attached to a sample from any point of treatment technology or any point of the water network [12].

The aim of this study was to measure FCM with other monitoring parameters and measurement under the 13N filter of the DWTP Nová Ves and to find the link between FCM and turbidity. On the basis of measured data, evaluation and proposal options focus on optimizing and assessing the frequency of rapid filter washing at the operating conditions.

2. Materials and Methods

2.1. Drinking Water Treatment Plant

For the evaluation of the rapid sand filter washing cycle using FCM, the central DWTP Nová Ves—Frýdlant nad Ostravicí in the Czech Republic (DWTP Nová Ves), owned and operated by the SmVaK Ostrava, a.s. company, was selected. DWTP Nová Ves is a part of the Beskydy group water supply system and has been operating since the 1970s (it has undergone several partial reconstructions over the years). Its current used capacity is 800 L/s, but it can reach the maximum output of 2200 L/s. The valley water supply reservoir Šance in the Beskydy Mountains is the raw water source for the DWTP Nová Ves, from which water is transported by gravity to the DWTP. DWTP Nová Ves supplies drinking water to almost 60 towns and villages in the Czech Republic in the regions of Frýdek-Místek, Karviná, Nový Jičín, part of Ostrava, and the border region of Poland (the Jastrebie—Zdroj district) [15].

In terms of raw water properties, the water is very soft, with a pH neutral over the year and a low level of biological and microbiological pollution. The basic parameters monitored reach average values of COD_{Mn} 2.4 mg/L, color 9.2 mg/L Pt, and turbidity 4.0 NTU. Raw surface water is fed to 20 sand rapid filters (European type WABAG) with a total area of 1940 m^2 with a filling of quartz sand grain size from 1.0 to 1.2 mm within the framework of one-stage coagulation filtration. The current filtration cycle, based on operational experience, typically lasts 40–96 h, at which point the filters regenerate/wash at the end of the cycle. The length of the filtration cycle depends on the quality of the surface water, the total daily water production, the pumping of recirculation wash water, the dosage of chemicals, etc. Regeneration of the filters is always performed in five filter units, at a frequency of twice a day, with five filters regenerated in the morning and five in the afternoon. The filter washing process combines air and water washing—2.5 min of air washing, 4.5 min of air and water washing at 300 L/s, and 2.5 min of water washing at 500 L/s. For oxidation of organic matter, chlorine dioxide is dosed into the raw water (before the sand filters), and aluminum sulfate (20% solution) is dosed as a coagulant before the filters. To adjust the pH, lime hydrate is dosed in the form of lime water, and hygiene is ensured by chlorine water and chlorine dioxide. The sludge from the filter-washing effluent with lime is settled in two horizontal sedimentation tanks and subsequently treated by centrifuge draining. In times of turbid state conditions, when turbidity is increasing due to excessive rainfall or snowmelt, the 1st separation stage is activated. It consists of flocculation with hydromixing and subsequent sedimentation in a lamella build-up, where the coagulant agent is combined with a polymeric organic flocculant [15].

2.2. FCM Measuring and Monitored Parameters

For evaluation of the washing cycle, the rapid sand filter 13N at DWTP Nová Ves was selected. The measurements were divided into two stages to cover different climatic periods (summer, winter). The 1st stage was carried out from 9 August to 23 August 2019, and the 2nd stage was carried out from 27 November to 18 December 2019. The current measured control parameters for the work filtration cycle were wash cycle, flow rate under the filter, average daily flow rate under the filter, the average flow rate per filtrate cycle, water production, times of pumping recirculation wash water (RWW), and turbidity—of raw water, RWW and water after filtration; next monitored parameters were physico-chemical and microbiology indicators (the list of monitored indicators is in Table S1). The newly proposed tested control parameters were parameters measured by FCM (the list of FC-measured results is in Table S1).

The 1st stage was the manual measurement of input data on the rented flow cytometer (FC) SIGRIST BactoSence (bNovate Technologies, Zürich, Switzerland), with the LDC—Live/Dead Count cartridge to determine the number of damaged/dead and intact/alive cells, followed by mounting under the 13N filter to monitor microbiological recovery during the filtration cycle in automatic mode, with the simultaneous monitoring of selected parameters during the measurement period. The time interval of the analyses and sampling was chosen to be 4 h, so 6 analyses were performed per day. Along with the FCM measurements, turbidity was automatically measured using the online photometer Aquascat 2 WTM A (Sigrist-Photometer AG, Ennetbürgen, Switzerland). At this stage, laboratory cultivation analyses—Heterotrophic Plate Count method (HPC) at 22 °C and 36 °C were carried out simultaneously; the flow rate under the filter 13N was monitored due to the pumping of the RWW, and finally, the instrument was tested under operating conditions.

The aim of the 2nd stage was to carry out more detailed measurements in the winter season, based on the trend observed after the 1st stage of measurements, with extended filtering cycles. The aim of this measurement was to obtain the necessary data to determine the link between FCM and turbidity, depending on the results of the previous measurements, and to ensure trouble-free operation of the instrument under operating conditions. As the optimal interval of measurements, a time interval of 2 h was chosen from 27 November to 28 November 2019, followed by measurements at an interval of 4 h, i.e., 6 analyses were performed per day. The following parameters were monitored during the measurements: filter 13N wash cycle length in hours; flow rates under filter 13N and production in L/s; and RWW pumping times and turbidity. The turbidity monitored was for raw water turbidity, RWW turbidity, and turbidity under the 13N filter, measured with the same above-mentioned photometer in the NTU unit.

Physico-chemical and microbial analysis of the water samples was conducted in the laboratory of the DWTP (SmVaK Ostrava, a.s., Ostrava, Czech Republic). All parameters were measured via the standard methods. All data sets were normalized using means and standard deviations of the variables using Microsoft Excel 2010.

3. Results and Discussion

3.1. The First Stage of Measurement

The average values of the number of live and dead, small and large cells per mL of water, and the percentage of live and large cells are presented in Table 1. The RWW sample had to be diluted 10 times due to exceeding the FCM detection limit. This verified that no correlation between cell count and organisms could be found, and a comparison of the measurements was made (see Table S2). The graphical representation of the so-called "fingerprint" in manual mode of RWW 10-times diluted sample by FC can be seen in Figure 1 (additional photos are in Figure S1). The quality of raw water is presented in Table S3.

Table 1. The initial data measured manually with the FC at DWTP Nová Ves.

Sample	Date and Time of Analysis	TCC [1] Cells/mL	ICC [2] Cells/mL	ICP [3] %	HNAP [4] %
raw water	9 August 2019 12:08	1,596,150	1,166,375	73.1	90.9
RWW [5] 10 times diluted	9 August 2019 11:38	894,500	489,877	54.8	90.9
RWW [5] recalculation	9 August 2019 11:38	8,945,000	4,898,770	54.8	90.9
13N filter	9 August 2019 13:17	633,398	577,288	91.1	88.7
inflow DWR [6]	9 August 2019 10:55	616,171	19,575	3.1	39.1
outflow DWR [6]	9 August 2019 10:16	542,900	14,733	2.7	38.8

[1] Total Cell Count (live and dead) per mL. [2] Intact Cell Count (intact or live) per mL. [3] Intact Cell Percentage ICP = ICC/TCC. [4] High Nucleic Acid Percentage HNAP = HNAC/ICC. [5] Recirculation Wash Water. [6] Drinking Water Reservoir.

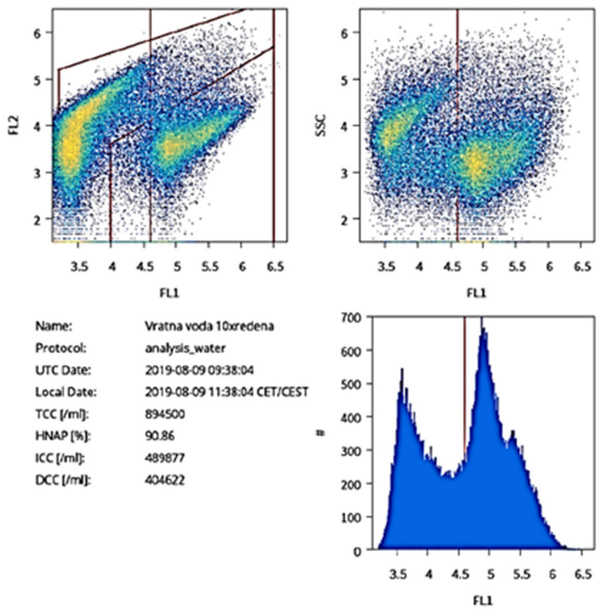

Figure 1. Data measured with FC Bactosence—"fingerprint" of WWR 10 times diluted sample (DCC—Death Cell Count).

The results of FCM prove that even high-quality drinking water contains from 100 to 1000 times more cells than can be cultivated by classical laboratory methods [16], i.e., the limits of cell counts cannot be set, according to the experience of Switzerland, which has "Flow Cytometry Analysis of Water Samples" included by the Swiss Federal Office of Public Health in Swiss regulations [17]. The limits on the number of cells depend on several factors, such as the source of water, the method of treatment, the method of sanitation, the place of measurement, the residence time of the water in the network, etc. In the analyses, it is necessary to collect the actual empirical cell count data and determine the limit quantity based on these data. The trends of FCM and turbidity after the rapid sand filtration are presented in the figures below.

Based on the measurements in the automatic mode, the measured data were processed graphically to show the length of the wash cycles, interleaved on the right axis in Figure 2, with the length of the filtration cycles reported in hours. The next parameter monitored was turbidity, whereby the FCM measurements on the right axis interleaved with turbidity in Figure 3, a relationship that can be seen between the turbidity increase and the microbial recovery increase. Due to planned downtime and an unplanned measurement outage, there was a noticeable disruption to the entire measurement, but the graph shows that by extending the filtration cycle, the filters were incorporated, cell counts stabilized, and gradually decreased. This can be observed in the measurement period from 16 August to 22 August 2019, even though there was a planned shutdown during the measurement period. Turbidity is measured in a very small range from 0 to 0.7 NTU. This parameter approximately follows the trend of the FC measurements and can be identified as one of the key parameters that can be related to the measurements made. Turbidity and the cell count itself are influenced by, among other things, the RWW pumping, where the cell count increase can be observed after the pumping is stopped in the next measurement but gradually declines to the values measured before pumping. Of course, a slight increase in turbidity can also be explained by the higher turbidity of the RWW. This parameter and its evolution were also monitored in the second stage of measurements. The prolongation of the filtration cycle could bring along, as a negative effect, a reduction in the flow rates under the filter due to clogging and fouling. Therefore, during the measurements, the flow rates under the filter were recorded to verify whether the extension of the washing cycle would result in a reduction in the capacity and flow rates through the filter. Based on these, it can be said that the filter cycle extending will not significantly affect the flow rate. Comparing the measurements from 14 August to 16 August 2019, the average flow rate is 36.48 L/s. Extending the filtration cycle from 16 August to 22 August 2019, the average flow rate is 35.88 L/s.

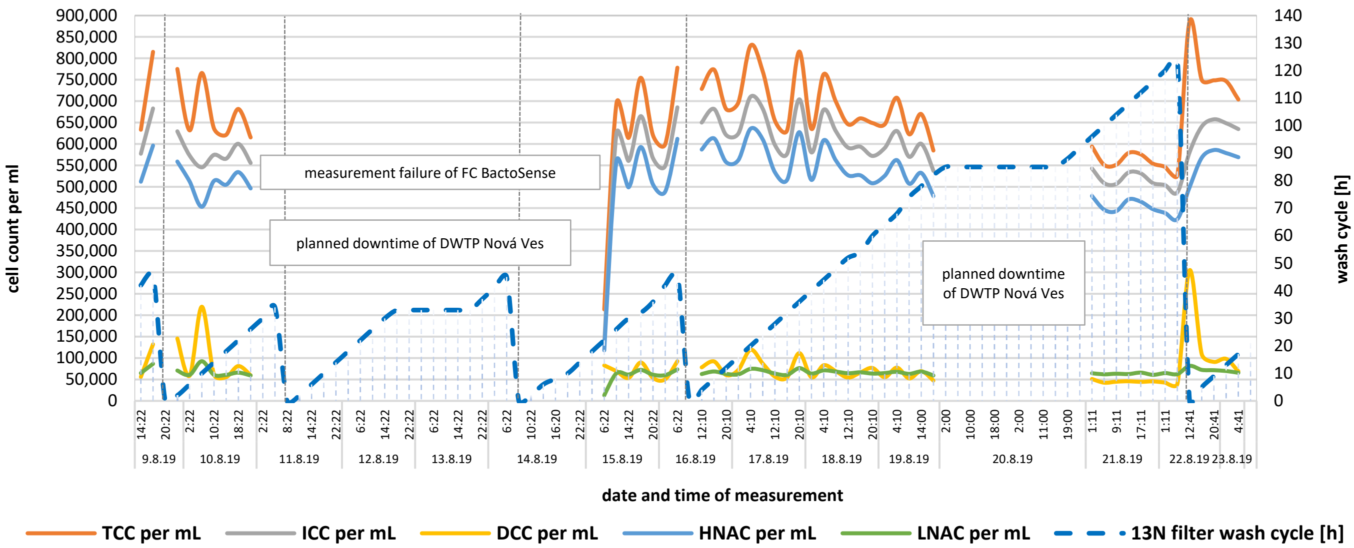

Figure 2. The 1st-stage measurement from 9 August to 23 August 2019: FCM and wash cycle.

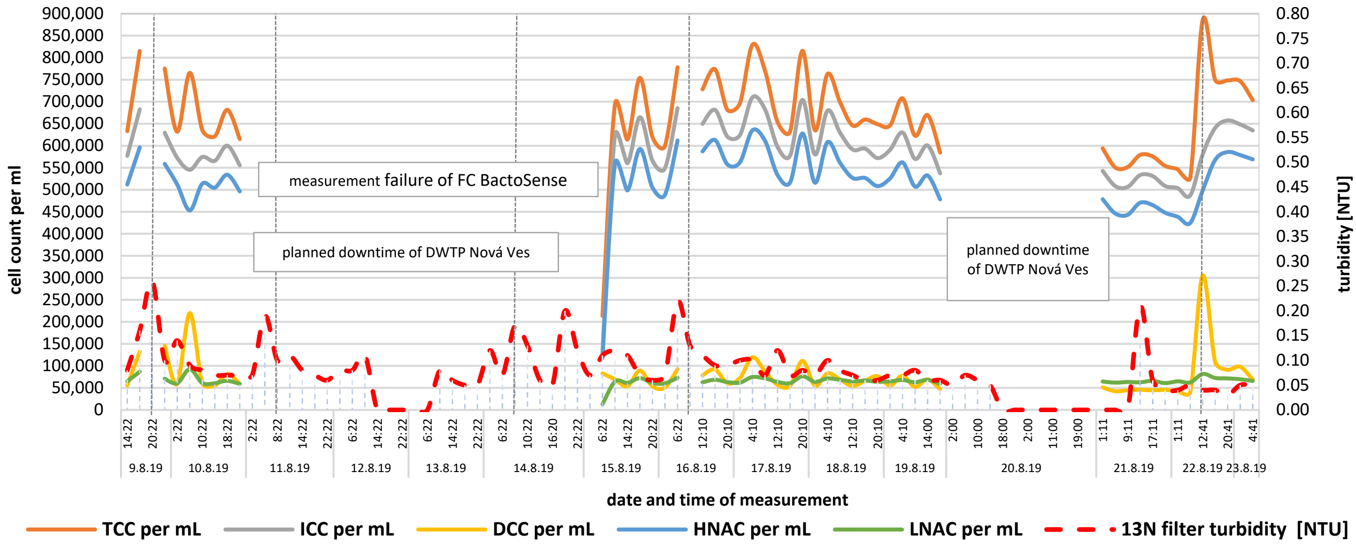

Figure 3. The 1st-stage measurement from 9 August to 23 August 2019: FCM and turbidity.

3.2. The Second Stage of Measurement

The evolution of Figure 4 evidently confirms the results of the first measurement; during the filter regeneration, there is a sharp increase in microbiological recovery, and there is a gradual decrease in the measured values over time. This is evident in the case of extended cycles, where, compared to shorter cycles, the time between cycles is so short that there is no flickering and stabilization of the values, and the microbiological increase is again observed during washing. In this context, it is necessary to take RWW, which enters the filtration process and influences the evolution of the measured values, into consideration. According to Figures 4–6, the pumping of the RWW is followed by the microbiological recovery increase, which turns into the values measured before the RWW pumping in the following hours.

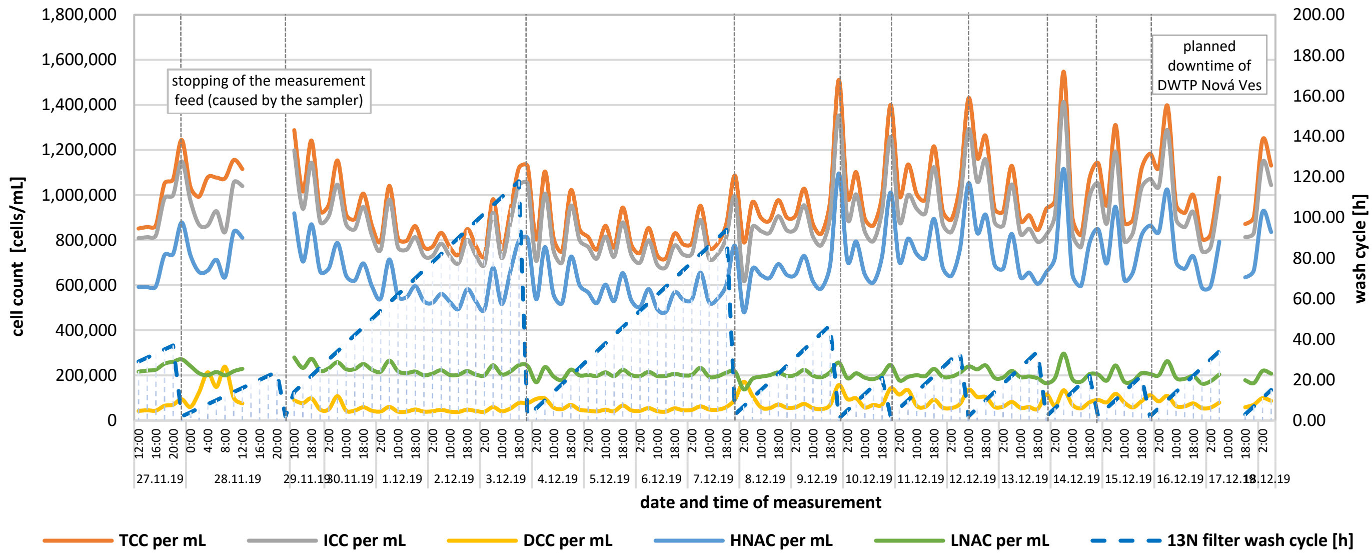

Figure 4. The 2nd stage of measurement from 27 November to 18 December 2019: FCM and wash cycle.

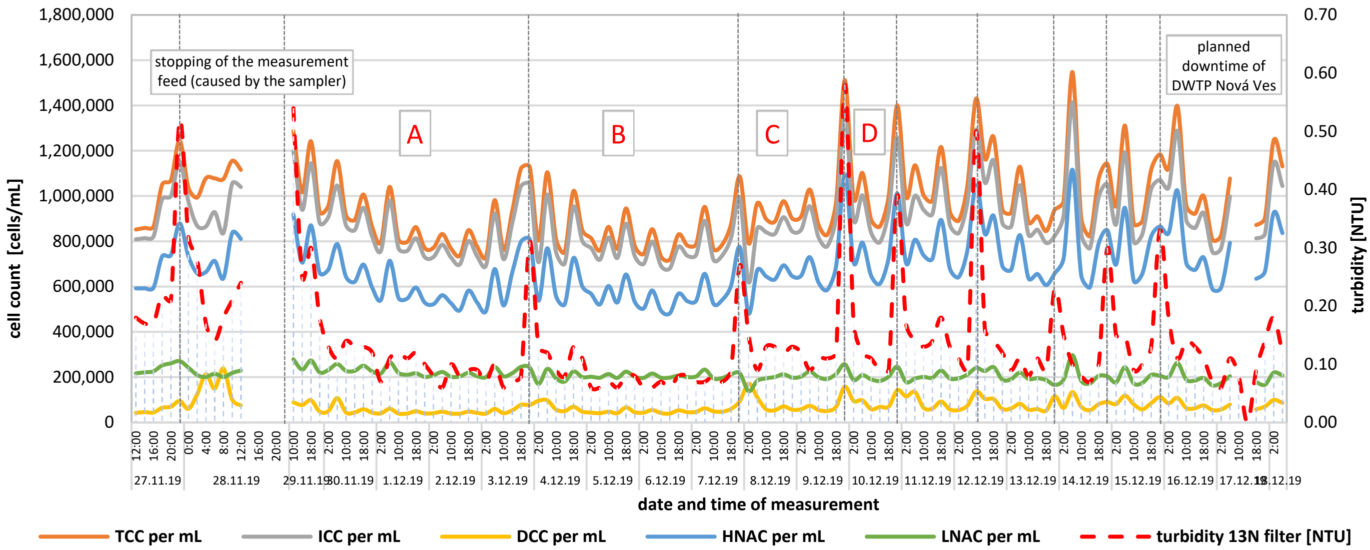

Figure 5. The 2nd stage of measurement from 27 November to 18 December 2019: FCM and turbidity (detailed **A**–**D** cycles are in Figure 6).

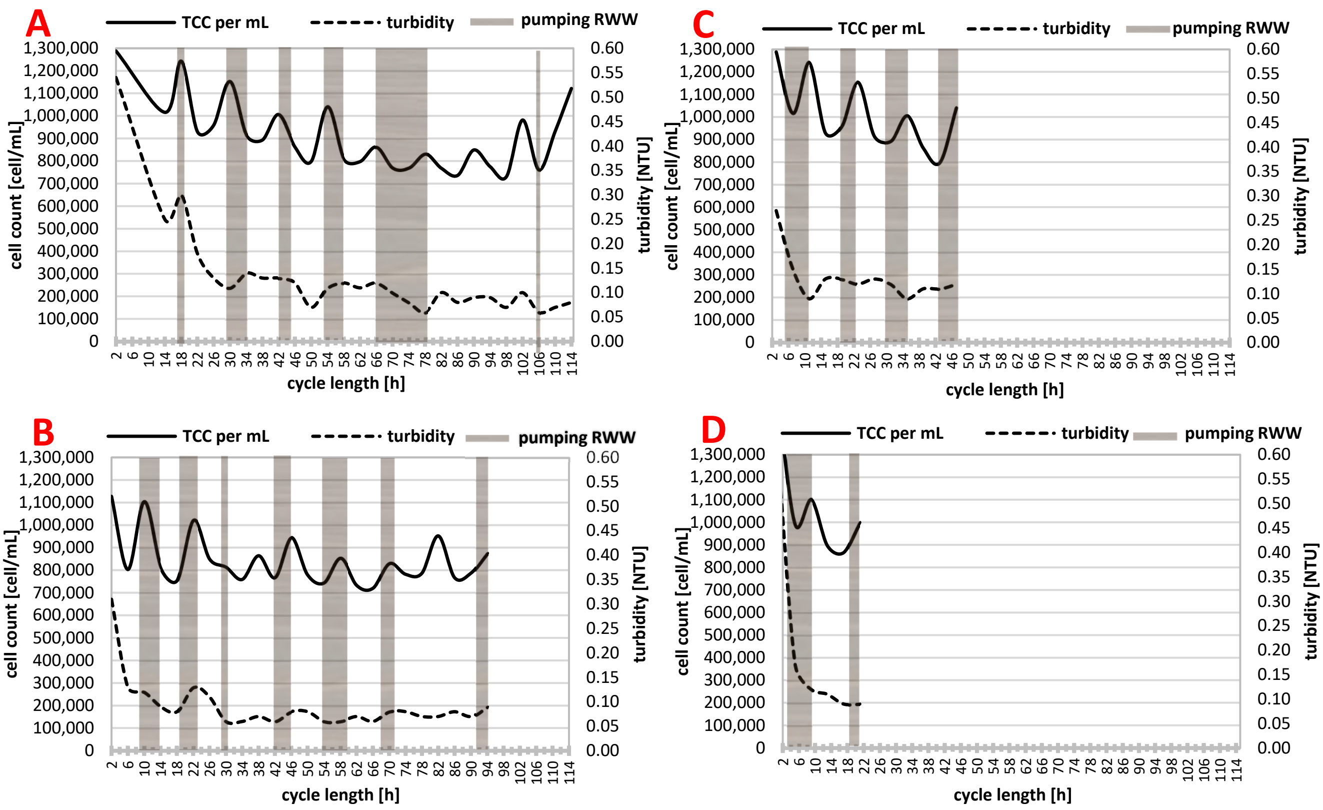

Figure 6. The 2nd stage of measurement from 27 November to 18 December 2019: detailed cycle length—TCC and turbidity affected by the RWW pumping (detailed **A**–**D** cycles marked in Figure 5).

In this context, the RWW pumping is not determinant for the filtration technology optimization, and while maintaining the method of pumping the RWW, an extension of the filtration cycles is possible. The measurements confirmed the evolution of turbidity, which was very similar to the measured values by the FC in the first measurement, so as already reported, the turbidity increase is directly related to the increase in microbiological recovery. This increase occurs again while the filters are being washed and the RWW is being pumped, which shows even higher turbidity values measured in the range of 3.7

to 60.2 NTU. For comparison, values in the range from 0.06 to 0.54 NTU are measured on the turbidity meter below the filter. In addition, the raw water turbidity was recorded as a parameter entering the technological process. Based on the increase in the turbidity of raw water, it is possible to consider its aggravated quality, which, especially for surface sources, is influenced by several factors. According to the above, the turbidity parameter can be considered to be the main one. The quality of raw water is presented in Table S3.

4. Conclusions

Water filtration is a relatively conservative area in terms of development and optimization. However, it is also an area in which important developments are constantly being made that can make the whole process more efficient. As part of the evaluation of the filtration cycle, the following parameters were monitored under operating conditions: length of the wash cycle in hours; the flow rate of the filter and the production; the pumping of the recirculating wash water; the physico-chemical and microbial analysis of the water samples; and turbidity and flow cytometry (FCM). The filtration mode was evaluated during the summer and winter periods.

The measurements performed and its evaluation show that the link between turbidity and FCM is possible. Similar trends have been observed, and there is evidence that FCM is more responsive, which would be more advantageous for the WTP operators, who could react faster if FCs were fitted. The only disadvantages to implementing the FCM in operation are the purchase price and ensuring the operating conditions for its flawless operation.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/engproc2023057009/s1, Figure S1: The DWTP Nová Ves: A—13N filter, B—FC BactoSence fitting under the 13N filter, C—Detail of the connection to the water feed in automatic mode; Table S1: The list of monitored physico-chemical and microbiology indicators in water samples; Table S2: The 1st stage—microbiology analysis: laboratory and FCM; Table S3: Laboratory analysis of raw water DWTP Nová Ves.

Author Contributions: Conceptualization, R.M. and P.M.; methodology, R.M.; validation R.M., P.M. and J.C.; resources, S.D.; data curation, R.M. and S.D.; writing—original draft preparation R.M. and P.M.; writing—review and editing, R.M., P.M., S.D. and J.C.; visualization S.D.; supervision, R.M. and P.M.; project administration, R.M. All authors have read and agreed to the published version of the manuscript.

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