Chapter 9

Counting totally matters – using GRUNDFOS BACMON for network monitoring

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9.1 INTRODUCTION

Water scarcity, ageing infrastructures, and emergence of new pollutants are all different factors resulting in the maintenance of water quality being one of the main challenges societies face in the 21st century. Degradation of water quality translates directly into threats to human health, limited food production, reduced ecosystem functions and into environmental and socio-economic challenges in general (UNESCO, 2015). Besides maintaining a good drinking water quality, a wish for better resource utilization has led to concepts like "Water Fit for Purpose" (Carpentier & Cole, 2018) and an increased focus on water reuse possibilities (Sgroi *et al*., 2018; Olivier, 2018). Altogether, these challenges put larger and larger demands to how we collect, treat, distribute, use, dispose, clean, and discharge water. Grundfos has over the years moved a lot of water with pumps. However, the emerging challenges has led us – and our colleagues in the business – to supplement the pump itself with surveillance, demand driven distribution to reduce leakages, and a range of dosing and disinfection products to not only move the water but also treat it. Lastly, digitalization of equipment has given opportunities to optimize and operate entire systems in a much more structured and coherent way.

The chapter is from the book *Microbiological Sensors for the Drinking Water Industry,* Torben Lund Skovhus and Bo Højris (Eds.).
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Yet, a desire to improve quality in all steps, reduce waste, and increase efficiency has increased the complexity in managing and operating water production and -treatment. A complexity that has put stronger requirements to how water quality is monitored, controlled, and maintained. Generally, the trend has gone towards seeing the entire network more holistically, exemplified by WHO introducing Water Safety Plans as such an approach: "*The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer*" (Bartram *et al.*, 2009).

Part of such a safety plan is of course to watch and control the water quality. Traditionally within water quality measurements, the results of water from yesterday are ready tomorrow. This is mainly due to the fact that culture-dependent methods are extensively used for water quality testing and these take time to obtain reliable results. It complicates the wish for water utilities to assert proactive actions in daily operations and hampers efficient tracing in case of unforeseen contamination events. Besides this, there is a broad distribution of pathogens that occur in water in a viable but non-culturable (VBNC) state such as *Campylobacter, Legionella, E. coli* and others (Li *et al.*, 2014), which thereby can lead to false negative results from such culture dependent methods (Zhao *et al.*, 2014).

In the other end of the temporal spectrum, faster measures do exist like conductivity and turbidity, which both operate in the order of seconds. Related to the concentration of ions in the water, conductivity gives information about the dissolved dissociated salts, while turbidity is a measure for how cloudy the water is and its ability to scatter light. However, neither of these faster methods tell anything about whether a change in water properties stems from microbiology. In Grundfos, we saw the need for methods that could help watch the water to inform operation of pumps, dosing, disinfection, and networks about the bacteria content of the water faster than by growing bacteria colonies in the laboratory. We thus saw a potential benefit in having a broad method that albeit maybe less specific than culturing methods could give rapid information about the general bacteria levels; i.e. if not in seconds, then at least in the order of minutes. After having searched for potential candidates without luck we decided to try and develop a solution ourselves. Being a mass producer and coming from the pumps and operations side, we were not as such looking for a complex laboratory instrument but rather an automatic solution applicable in the field next to pumps and other equipment and being relatively easy to operate.

A decade later came the first initial releases of GRUNDFOS BACMON sensor units into the market. By supplementing, and to some extent replacing, manual sampling, BACMON offers a way to monitor a network by means of total bacteria- and non-bacteria (abiotic particles) counts. Automated batch sampling technology delivering total bacteria counts in minutes without addition of chemicals can be installed at selected key points, connected, and compared directly online in a common interface. Before going into the entire functionality of the connected system, first a closer look at the sensor unit being installed at the sampling points.

9.2 TECHNOLOGY AND SOLUTION

So, how can bacteria be counted in the order of minutes? In essence, a BACMON sensor unit can be described as an intelligent microscope utilizing 3D image recognition techniques to count and classify objects. A water sample is held still between two windows in a flow cell and then more than a thousand pictures are taken of that water sample. With different imaging techniques, it is then possible to track and identify all objects in the images of the water sample. On each individual object, the sensor unit extracts a set of features, compares these to a learned set of characteristics, and from there classifies each object as belonging to either of two groups: bacteria or non-bacteria. After adding it all up, the count is reported, the flow cell flushed, and the system is ready for the next sample.

9.2.1 Mimicking the human brain a bit

One can compare the inner workings of the BACMON sensor unit to the human brain. As kids, we are presented with images of humans, animals, toys, cars, houses, and other objects again, and again, and again. Slowly our neural network learns the features of e.g. a human being: face, arms, legs. We learn to distinguish 'this is a person' and 'that thing over there is a dog'. Notably, without having been presented to a picture of every individual human being in the world we – over time – learn to generalize. By finding the right features, we can even classify persons we have never seen before as being just that: persons. This analogy can be used on BACMON. Here an artificial neural network has been trained by presenting it with a very large number of very carefully prepared samples of different bacteria, other objects, and various mixtures, in order to learn which objects are bacteria by looking at their features. More than 50 different features are extracted from each object in the image. Some are linked to spatial parameters of the objects like e.g. area, perimeter, how round, how long. Other parameters are related to image properties like contrast, how is light scattered around objects, how is light shining through etc. Details about bacteria types, suspensions, and mixtures used for training and validating the instrument can be found in (Højris *et al.*, 2016).

With persons we can, just from looking, not tell their name, and whether they live in the Netherlands, UK, or Lithuania but with relatively high probability we can still count them as persons. The same goes for BACMON; it cannot tell specifically which bacteria are present or whether they are alive or dead. This is comparable to the skills of a human being. By just quickly looking at a person lying on the floor, we can have a hard time determining whether we are dealing with a dead person or merely one sleeping. Of course, if the head is in one corner and the body in another, we are not in doubt. Same for BACMON, if the bacteria have disintegrated by e.g. chemical disinfection, and thereby undergone a change in morphology, the objects or fragments would count as non-bacteria. Likewise, as the sensor unit cannot deliver any specific pathogenicity information, sequencing or other advanced methods can be needed as sometimes even the same species can express different pathogenic properties (Alberts *et al.*, 2002). Instead, the sensor unit can give a total bacteria count in minutes.

The fact that BACMON operates by just 'looking' and thereby avoiding handling e.g. reagents with a potential shelf life, is seen as one of the clear benefits of the approach. Even though full specificity, viability, and pathogenicity assessed in seconds would be a long-term ideal to strive for, simplicity, practical use, and speed has deliberately been prioritized over specificity.

9.2.2 How does it compare?

The sensor unit simply counts all the particles in the water sample and classifies which ones are bacteria and which are non-bacteria. The result is an absolute number, telling how many there physically can be seen and not how many there are, compared to a baseline. This fact is important to remember when wanting to assess results from the individual sensor unit or when comparing across sensor units: one is dealing with actual numbers.

Validation of the method has been done up against e.g. total direct cell count (TDCC) through DAPI staining and fluorescent microscopy, which is a well known manual, technique to perform a total count of bacteria (Porter & Feig, 1980). By adding increasing amounts of yeast extract to act as nutrition for bacteria, and allowing an incubation time, one can get different growth dynamics and see how well BACMON compares to manually counted references. Results from such a test are depicted in Figure 9.1.

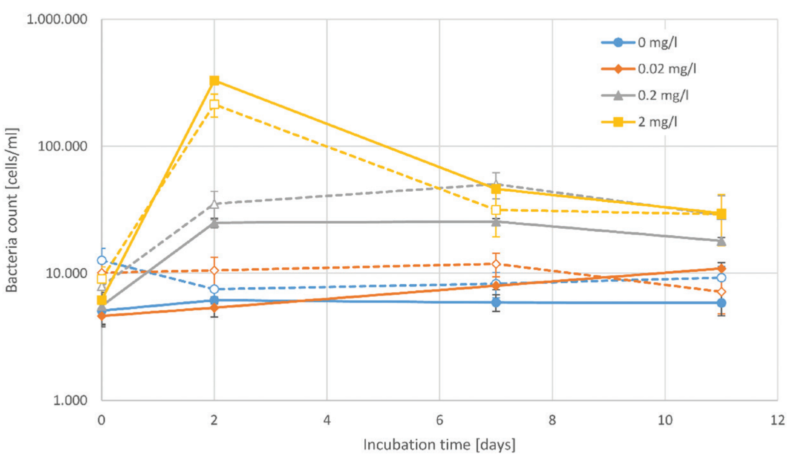

Figure 9.1 Different amounts of nutrient were added to tap water and growth patterns measured by BACMON (solid lines) and TDCC (dotted lines). The two methods correlate well, expressing the same dynamics. Importantly, also after a high count, BACMON follows the TDCC downwards, when bacteria start to decay (Illustration adapted from Højris *et al.*, 2016).

BACMON delivers results in bacteria per mL and can count as low as zero. It ‘looks’ at the water and if none of the objects in the analysed focus field in the flow cell are classified as bacteria, BACMON will report zero (0 bacteria per mL). However, the challenge is to ensure that the small water sample in focus is representative of the entire stream. This is difficult. The BACMON sensor unit analyses a volume of 6 μL in the flow cell. If one object is classified as bacteria, this will then lead to a count of 167 bacteria per mL (as 1 in 6 μL equals 167 in 1 mL). However, the sensor unit is designed for drinking water and here the numbers are normally much higher. In e.g. a total bacterial count analysis of more than 50 samples of drinking water from various distribution networks and rural communities in Finland led to a median of 55.784 cells per mL (Ikonen *et al.*, 2013). This is in line with the experience from BACMON readings across Europe, where, under normal conditions, the total bacterial counts can easily range from 1000 to 100,000 cells per mL depending on the location and source. What is worth noting, though, is that *within* the same source, the variation under normal conditions is much lower. How low depends on a lot of operational factors though.

With a BACMON sensor unit, there are more than 100 measurements the first day of installation and more than 1000 samples of total bacterial count in the first week. So, even though BACMON delivers an absolute number – and not a reference to a baseline – the effect is that after installation one relatively quickly gets an understanding of what *is* actually the baseline for the water in question at the specific sampling point. An example is a customer in EU, where sensor units were installed at different Slow Sand Filters (SSF) to monitor microbiological dynamics when skimming the filters. Despite being more or less ‘the same’ unit operation, one SSF consistently had more than double the number of bacteria per mL in absolute numbers when compared to the other; a comparison that then served as the entry point for further investigations into the cause and thereby a way for the customer to optimize the operation and implementing best practices across.

Many ask how to compare a BACMON reading to plate counts or CFU measurements done in the lab. This is not directly possible. A plate count is done on specific growth media and at temperatures favouring specific bacteria (e.g. 22°C or 37°C) whereas the BACMON sensor units count everything; also, those bacteria growing at 8°C or those that are viable but non-culturable. The result is a broader and more complete, *total* count.

Being an absolute measure, one can also compare individual BACMON sensors units. Yet, as shown in Figure 9.2, setting up five sensors to measure the ‘same’ water from the same water line will lead to small variations. This is important to have in mind when ensuring that the sampling point draws a sample as representative as possible from the water line. One cannot measure all water passing by, but always a sample. However, the fact that one can now measure e.g. total count much faster than traditional methods allows the method itself to even out these variations over time. Had the sensor units in Figure 9.2 been installed for example 10 km apart, it would be an interesting indication of water system integrity.

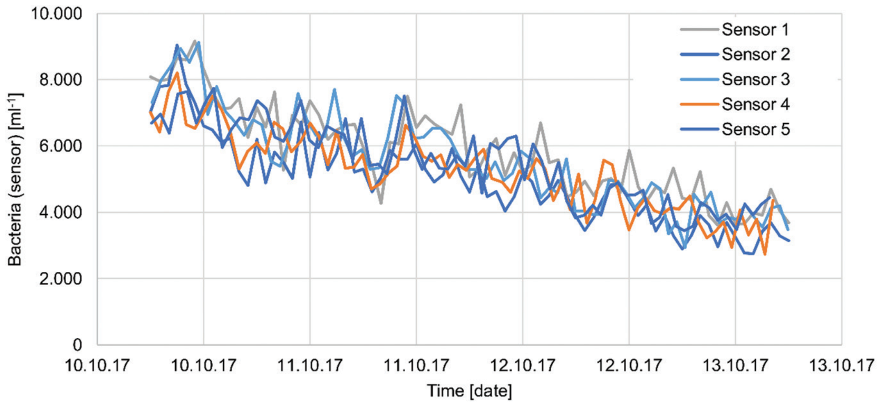

Figure 9.2 Five BACMON sensor units installed to sample from the same water source by means of a manifold distributing the water (Danish drinking water). The variations arise because one is not measuring on exactly the same water sample. However, the five units expressed the same trend, level and variation during the test.

Speed and comparisons of different sensor input from different sampling points can also be obtained with other methods of course. Turbidity is once such instrument which rapidly measures the cloudiness of water and has been used as an indicator for water quality for decades. BACMON has been compared to turbidity in various ways, where one is illustrated in figure 9.3. Experimentally trying to simulate a water contamination, clean water samples were spiked with different amounts of various contaminants. Depending on the source, the reading from the BACMON sensor unit reacts 10 to 100 times before the turbidity signal.

Besides a relatively higher sensitivity, one thereby gets the additional benefit of knowing, not only if the water is cloudy but also, whether that 'something in the water' is of microbiological origin or stems from suspended abiotic particles.

9.2.3 Air bubbles, biofilm, and fouling taken into account

With thousands of bacteria per millilitre being present in regular drinking water, fouling will occur on the inner surfaces of the flow cell used in the BACMON sensor units. When this happens, the (disposable) flow cell is exchanged and the sensor unit continues its operation. A status indicator is continuously reporting the present state of the flow cell giving the operator a chance to follow it and schedule an exchange, at a predefined level. Local conditions are determining how 'potent' the water is in terms of fouling. In non-chlorinated Danish drinking water, there are about 1 to 2 months between the need to visit the sensor unit and exchange the flow cell. Status of the flow cell can be given because there is a camera in BACMON that actually 'looks' at the water and the flow cell. If something is stuck on the window, it can be seen in the images. This is used to generate the flow cell status but also to take into account if other disturbances are present. Deliberately, the focus field for the imaging is set to be in the middle of the flow cell between the two windows. This means that if sediment has settled on the bottom, it is not in focus and can be ‘looked through’ and focus kept at the particles and objects held fixed under pressure in the middle of the flow cell. However, the fact that these disturbances can be seen also means they can be taken into account when interpreting the data. If an air bubble is rendering the image acquisition difficult in a part of the flow cell analysis, this area is consequently discarded and not included in the analyses; if needed additional pictures are be taken of areas without the air bubble, keeping good statistics behind the count reported.

		Bacteria	Abiotic particles	Turbidity	TDCC
Soil [mg_{dry}/l]	0,067	-	-	-	-
	0,2	-	-	-	-
	0,67	-	-	-	-
	2	-	-	-	-
	6,7	-	+	-	-
	20	+	+	-	+
	67	+	+	+	+
	200	+	+	+	+
Waste water [ml/l]	0,003	-	-	-	na
	0,01	-	-	(+)	na
	0,03	-	-	-	na
	0,1	-	+	-	(+)
	0,3	+	+	-	+
	1	+	+	-	+
	3	+	+	-	+
	10	+	+	+	+
Pidgin faeces [mg_{dry}/l]	0,017	-	-	-	-
	0,05	-	-	-	-
	0,17	-	-	-	-
	0,5	+	+	-	+
	1,7	+	+	-	+
	5	+	+	+	+
	17	+	+	+	+
	50	+	+	+	+

Figure 9.3 Experiments from various amounts of contaminants added to non-chlorinated Danish tap water. The boxes with a ‘ + ’ sign indicate when the signals from the different methods are significantly higher than the background readings (Student’s t-test with 98.5% confidence). Boxes marked ‘(+)’ indicates responses significantly lower than the background. ‘na’ indicate samples unable to be enumerated due to too low concentrations. The Bacteria and Abiotic particles columns are from BACMON and it is seen that they respond at 10 to 100 times lower concentrations compared to the turbidity meter and at the same contamination levels as total direct cell counts (TDCC). (adapted from Højris *et al.*, 2018).

9.3 OVERALL CONCEPT

The BACMON solution is basically comprised of three elements (see Figure 9.4):

(1) A number of **Sensor Units** strategically placed e.g. at the water source, in the treatment train, and in the distribution network. The sensor units are sampling the water automatically and deliver their data to a server.
(2) A cloud-based **Water Quality Management** server, which manages the individual sensor units, provides integrity measures, and collects the data.
(3) The server allows for auxiliary data to be entered into the server; thereby allowing for information coming from outside the BACMON system to be stored, compared, analyzed, and accessed in combination with the existing data.
(4) Various **Interfaces**, which can then be used to view results, compare data, and work with the analyses in real time.

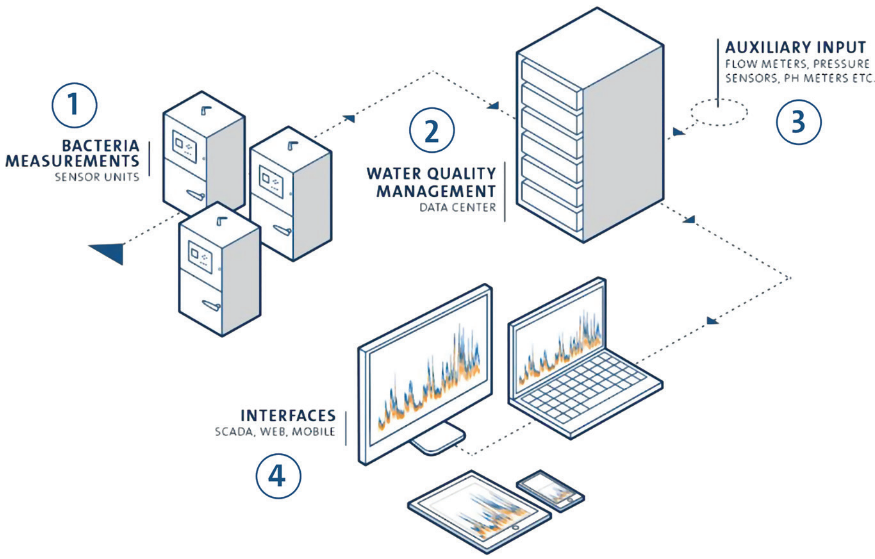

Figure 9.4 An overall illustration of a BACMON solution. A number of Sensor Units (1) send their results to a Water Quality Management server (2) into which other inputs in principle could be given (3) and from there extracted to different Interfaces (4).

Installation of the sensor unit of course requires access to the water and a suitable drain, but besides that only power and a data connection is needed to get started measuring. Typically, the water is sampled from an existing sampling valve or a new access point is created equivalently to the principles behind establishing representative sampling points.

The Water Quality Management server holds the data, provides easy access to historical views on each sampling point and allows for advanced, computationally demanding analyses to be performed; both on data from the individual sensor units and jointly across the entire installation for the network in question. Monitoring the results is done by means of extracting the data to an interface of preference (iPad app, web browser based tool, SCADA system, setting up SMS/email alarms, etc).

Comparisons within a network will aid an operator to compare unit operations and optimize daily schedules and handling. Integration and use of other measures both online and offline will supplement and enrich the bacteria analyses and gradually it might help projecting and predicting from manual samples while at the same time perhaps guide where to best take the next manual sample for more detailed analyses to learn more and most. Eventually, the perspective will be to compare unit operations to unit operations, production to production, network to network, and broaden that view across borders and applications.

The benefit of having multiple sensor units combined in a single interface is, amongst others, to be able to get an overview of the bacterial levels across points in the entire network (see figure 9.5). With e.g. a simple 'traffic light' colour-coding system one can quickly see whether everything is ok (green), if something requires attention (yellow), or if a situation gives rise to an alert (red). The threshold levels associated with each colour code may be set individually in each case to reflect the 'normal' baseline situation and elevated alarm levels. In case of any unforeseen events, a distribution of online sensor units thereby also facilitates an assessment of the extent of the incident and aides a faster tracing and potentially confinement of the source or at least provides the possibility to focus in the search for a cause (source tracking).

To better compare against other existing measures (like pump and valve actions, pressure, temperature etc.), water utilities prefer often to incorporate the data in existing monitoring and operating systems. There is a multitude of different systems and the way one integrates BACMON data is via an API (Application Programming Interface) which, in a standard way, defines how one to read the data. An example of such integration is shown in Figure 9.6. The same interface is used when e.g. getting weather data from meteorological service servers and integrating those to anticipate flooding.

9.4 FROM DUSK TILL DAWN – APPLICATION CASES

Keeping the above comments about specificity in mind, what the BACMON solution *is* capable of delivering, is a total count of bacteria in minutes. This means in practice that one suddenly gets microbiological insight about the sampling points selected more than hundred times per day instead of perhaps once a day, week, or month. And why does this matter? It provides a broader, fuller picture of what is going on in the water.

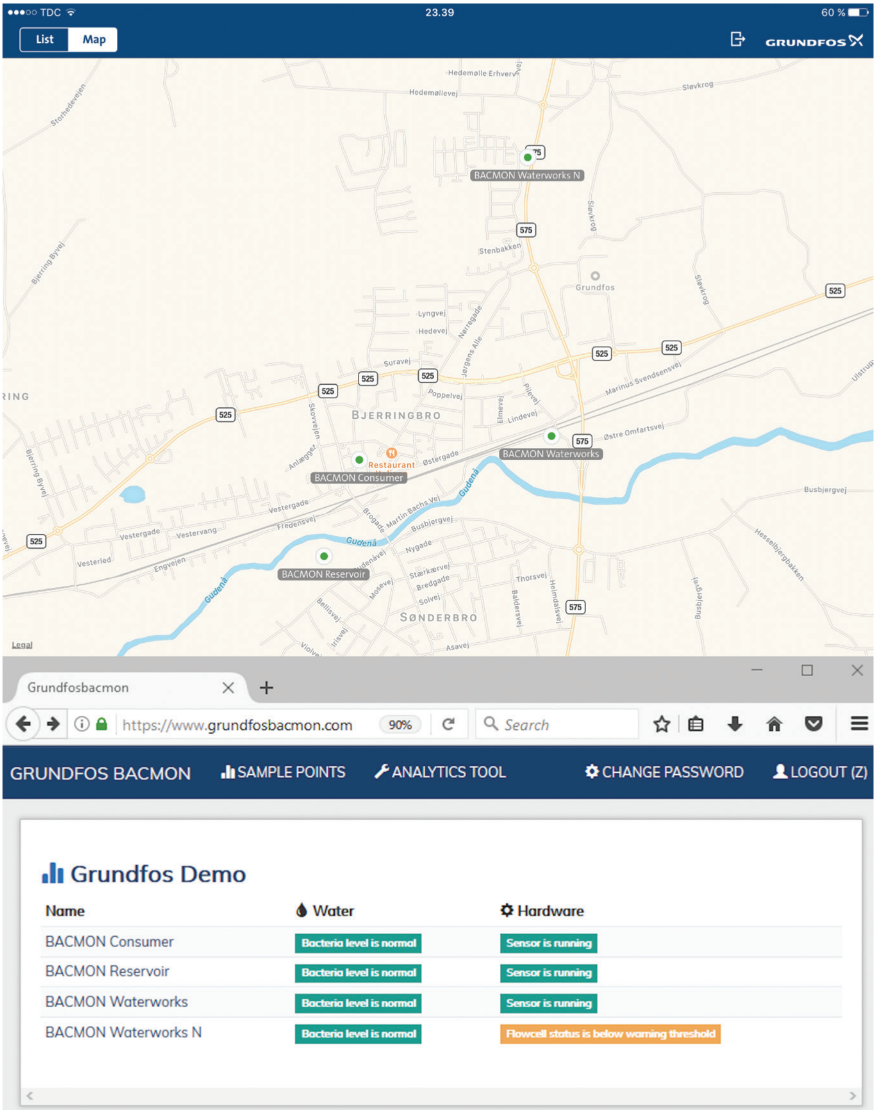

Figure 9.5 Top: Screenshot from the BACMON iPad App showing the location of distributed sensor units on a map along with an indicator of state (green, yellow, red) providing a quick overview of the situation and guides where to focus if something deviates (placement of sensor units for illustration purpose only). Bottom: Screenshot from the web interface showing a status screen of the individual sensors. In the example here, flow cell status was below 50% and the system has gone to a warning state, so the operator can plan for an exchange.

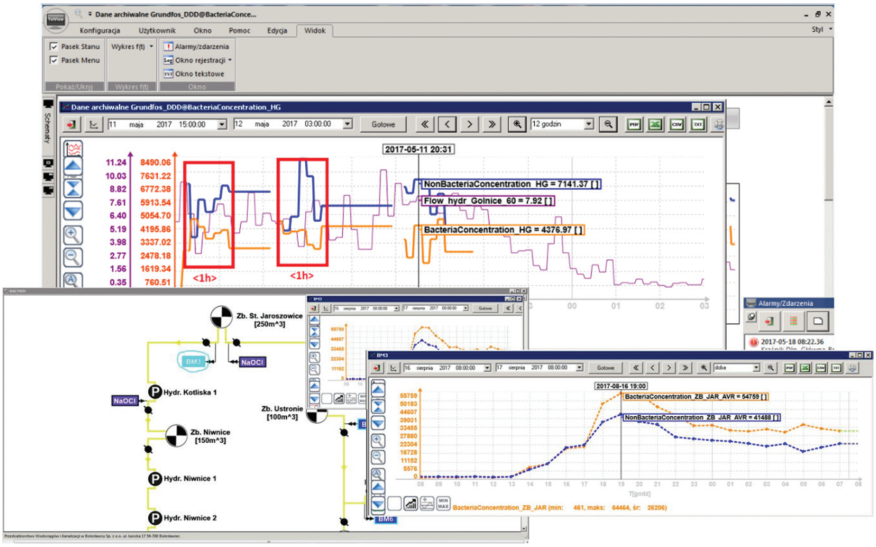

Figure 9.6 An example of integration of BACMON data directly into the SCADA system of a water utility. They use a number of different views/windows to operate their entire network and some are shown here, to illustrate how BACMON is integrated deeply into the individual views of the entire system and not just as a stand-alone window. Bottom left is a stylized map of their network and the sensor unit locations are visible as icons in this. The three windows upper right are different views used to manage the network where BACMON readings are integrated. In this way comparisons can be made directly to e.g. flow and other existing measures and thresholds and logic can be set up to alert the personnel in operation through the existing alarm schemes and protocols.

In 2017, the EU Commission had the 1998 Drinking Water Directive (DWD) under review. In their so-called 'REFIT Evaluation' they write: *"Special attention should be paid to the relevance of microbiological parameters, where 'new' pathogens not considered in the current DWD present real challenges."* (European Commission, 2016) It is not a claim that BACMON is the 'silver bullet' solely addressing these challenges but definitely it adds a perspective that previously has been difficult to get with current methods. It is fair to say that with its total count of bacteria in minutes, BACMON has not yet been installed without learning something new about the system in question. A few cases follow to exemplify such installations.

9.4.1 Flushing filters

In production of drinking water, sand filters of various types are widely used to reduce the number of bacteria and remove unwanted solids. Being an integrated part of the production, the water quality is most often assessed in totality and not around the sand filters specifically. In Figure 9.7 is an illustration of the total bacteria count from a waterworks. Clearly, it is seen how continuous monitoring gives a totally different insight to the dynamics involved in running the water work than infrequent grab sampling can deliver alone.

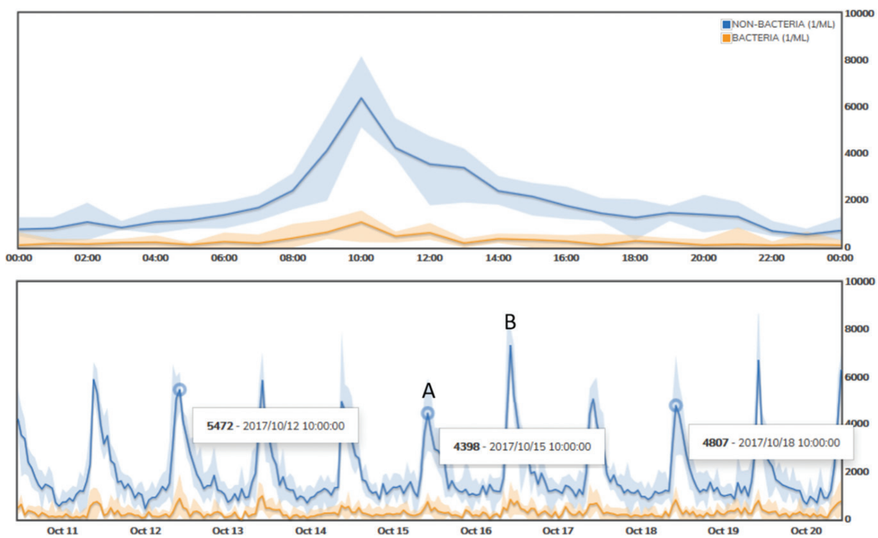

Figure 9.7 Top view: Seen as an isolated event, it might seem alarming at first glance, however, a (trained) water utility operator will recognize the time of day to match a filter flush. Bottom view: Even an untrained eye will see a clear pattern when looking further back in time; an effect one does not get by grab sampling once a day. If mapping against other information, like e.g. knowing the time for filter A and B being flushed respectively, one might learn something about the state of operation from the fact that the numbers are almost doubled when flushing the latter.

Individual filter flushed can be investigated and peak conditions, settling times, residual effects, and distribution of such events can be monitored in the system. Even more, when one starts to map filter flushes (as seen in Figure 9.7) to, for example, flow, filter number being flushed etc., one can get more information. Users of BACMON solutions have reported how they discovered that the sand media of certain filters needed replacement, as when these filters were flushed, the peaks were always higher than when other filters were flushed.

9.4.2 Network overview and optimization

In Figure 9.8 is a map of part of the network from a Polish water works where a number of sensor units are installed in a BACMON solution to monitor the daily operation. At some point, the water works had a planned renovation of a clean water tank in one of the water works and BACMON was used to follow the bacteria levels in the clean water tank while flushing before taking it back into operation. A view of the bacteria levels in the renovated tank can be seen in Figure 9.9.

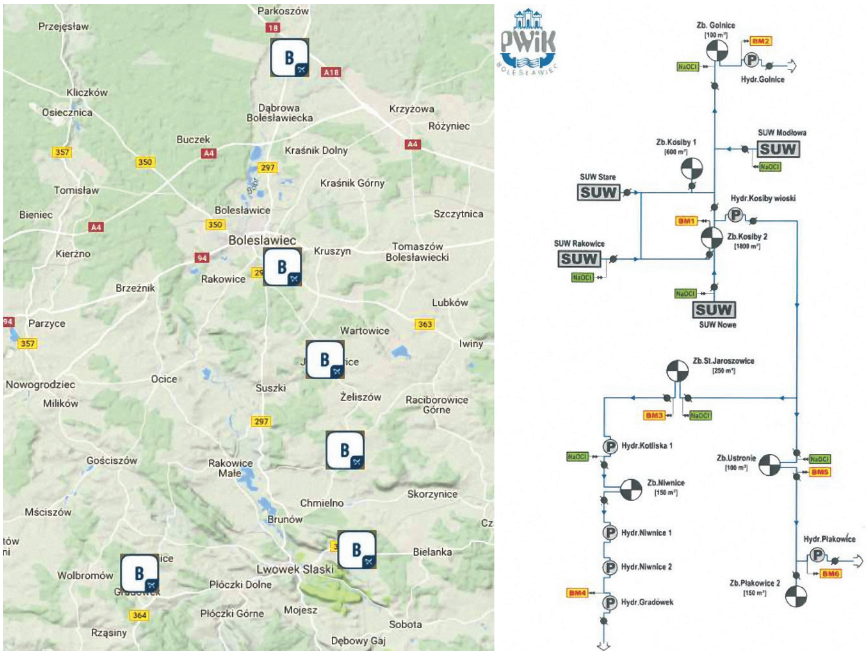

Figure 9.8 To the left an overview of how BACMON sensor are spread geographically to cover different areas of a water utility's production and distribution network. When coupling the geography with a Geographic Information System (GIS) and with sensor units installed in strategic important points in the distribution network, the water works has a better overview of how potential challenges might spread and it provides a way to isolate areas and better trace the origin in case of any unforeseen events. To the right, a detailed mapping of where the sensor units are installed in relation to the various process steps and a way for the water utility to get an overview of the entire operational parameters available.

Together with the flushing of the tank, the network was monitored while also adjusting chlorine dosing, to be in control of the distribution when recommissioning after the renovation.

The water works has the BACMON readings integrated into their SCADA system. By coupling the individual readings with the geographical and/or procedural placement in the network, they could follow the various bacteria levels, flow, conductivity, and other measures by direct comparison and use this to guide the operation and when manual samples were required to be taken, to release the renovated clean water tank to be taken back into production (see Figure 9.9).

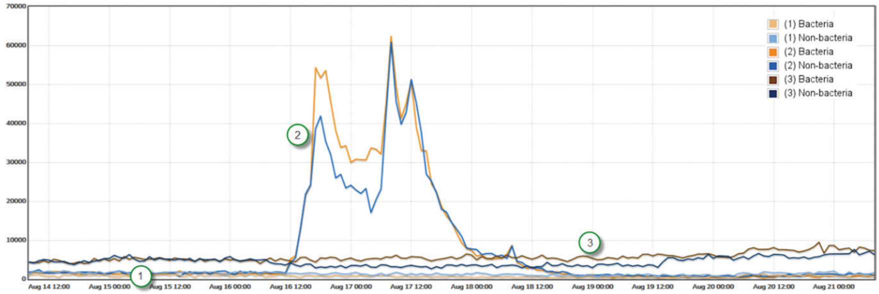

Figure 9.9 Watching the water coming from the water works (1) and comparing the reservoir (2) to downstream reservoirs (3) and pumping stations, the water utility could follow the effect of their renovation closely and have a strong indication of when the levels were back to normal and that the recommissioning did not lead to any unwanted side effects in the later stages of the network. This was confirmed by traditional laboratory samplings, which were guided by the BACMON readings.

Renovation of a clean water tank is not a new thing and can of course be done without a BACMON solution. However, hopefully it is clear how the online monitoring of bacteria levels in the network dramatically changed the insight into the effects and state of the production and distribution system along the way; thereby leading to a safer and more efficient recommissioning of the plant including documentation of the intermediate levels and system states. Also, the case hopefully serves as a general example of the strength in having a number of sensor units combined in a solution, to be able to follow, compare, trace, and watch how effects distribute and spread – or does not spread as in the renovation case – and thereby gives a holistic view of the entire network.

9.4.3 Red alert in food production

Besides being a general operational parameter to look at, an installation monitoring the total bacteria count several times an hour can also be used as an early warning or event detection assistant. In a Danish dairy processing plant, they have BACMON sensor units installed to monitor the intake water being used at several points in the production processes. At some point, a renovation of the distribution system outside the dairy plant went disturbingly wrong. The utility delivering the drinking water for the facility was renovating a pipe and by mistake during the renovation, dirty water was led 'the wrong way' through the installation and thereby into the inlet of the dairy processing plant. In Figure 9.10 it can easily be seen how suddenly rather low baseline levels was replaced by surprisingly high numbers.

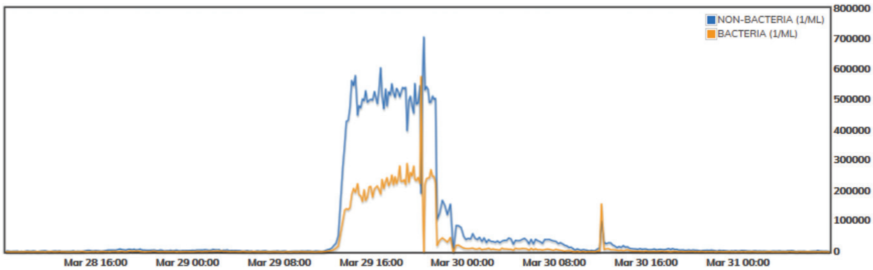

Figure 9.10 The concentrations from the BACMON sensor unit monitoring the inlet water quality at a dairy processing plant. A contamination stemming from pipe renovation external to the production site is evident and in the particular case so massive that the entire production had to be closed down and cleaned. Generally, the case is an example of the early warning and event detection potential in having a sensitive sensor unit installed monitoring the water quality in the order of minutes.

The dairy plant could see even with visual inspection that the water had gone bad. The site has three BACMON sensor units installed, one at the inlet and two in different sections of the production. Remains of the contamination were seen in the signals from the more remote units as well and it was decided that the entire factory needed to be closed down. A very unfortunate situation where water was then transported in tanker trucks to flush the lines and get everything cleaned before production was resumed. Even though the case in question was so massive that visual inspection of the water could tell the trouble, the example serves as a general illustration of how the temporal resolution of BACMON in many cases will enable the solution to function as an event detection mechanism and provider of an early warning.

9.5 FUTURE PERSPECTIVES

The pressures on our water resources are ever increasing and the demand for good water quality management practices follows. Broader and more frequent analyses are required to supplement grab sampling to ensure that we can maintain safe drinking water for many years to come.

The ability to analyse water quality and deliver total bacteria counts in minutes is a reality with BACMON: a relatively fast, simple, and intuitive way to get an absolute measure of the microbiological levels of the water. No doubt, the bacteria count in itself is a big help and improvement in operating the installations already being monitored out there. However, one must also recognize that BACMON is a novel solution and total bacteria count in minutes is a relatively unfamiliar measure to have available for water professionals. One can therefore only speculate how things can evolve from here. No doubt, changes on the individual sensor unit level can and will be analysed in greater detail as more and more units get into operation.

Levels, trends, anomalies, patterns, and behaviour in general will more and more be recognized and acted upon in an increasingly efficient way, the more water runs through these sensor units and the more historical data gets collected. A natural development would be to start integrating some of that collective knowledge 'back into the systems' so that installations can learn from each other; most likely anonymously, yet effectively.

9.6 REFERENCES

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