Showcase

Title: Development and Implementation of QA / QC Procedures for Online Monitors Enabling Their Use in Real-Time Control for Drinking Water Treatment

Sector: Drinking water (treatment):

☒ drinking water sources
☒ drinking water treatment
☐ drinking water distribution
☐ wastewater collection / influent
☐ wastewater treatment
☐ wastewater effluent / receiving water
☐ other

Utility: Waternet, Amsterdam, the Netherlands

Date: 2012

Introduction & Background Information

Waternet is the water cycle company for the city of Amsterdam and its surroundings. Waternet is the only water utility in the Netherlands responsible for the entire water cycle: drinking water treatment and supply, wastewater collection and treatment as well as management of surface water quality and quantity. Waternet was created in 2006 by the city of Amsterdam and the Amstel, Gooi, and Vecht Water Boards[1], unifying all operational activities related to water management, supply and treatment in the Amsterdam region in one organization.

Before the creation of Waternet, the city of Amsterdam had its own drinking water company (Gemeentewaterbedrijf Amsterdam, GWA) and a separate service for management of surface waters and wastewater collection and treatment. The Amstel, Gooi, and Vecht water board, furthermore, was responsible for wastewater collection and treatment as well as surface water management in the region to the south-east of the city. All these activities were merged into Waternet.

Waternet supplies drinking water to the Amsterdam metropolitan area, which has a population of well over 1 million, and to Schiphol international airport. In addition, Waternet acts as a wholesaler of drinking water, supplying water to neighboring water companies PWN and Dunea. Waternet has average daily production of 234,000 m^3 of drinking water. Waternet also collects the wastewater from the city and region under the administration of the water board, with a total population of 1.3 million, and operates 12 wastewater treatment plants, treating 343,000 m^3 daily.

The drinking water at Waternet is produced from two different sources: seepage water from the Bethune polder, a low-lying polder to the south-east of Amsterdam where large amounts of high quality groundwater well up to the surface. This source covers about one third of Waternet's water demand. In addition to this seepage water, water from the River Rhine is used for the production of drinking water. This water is taken in from the Amsterdam-Rhine Canal, which connects the city of Amsterdam to the Lek and Waal rivers, both distributaries of the Rhine. The Bethune polder source can be supplemented by Amsterdam-Rhine Canal water as well, but this

[1] The *waterschappen*, or Dutch Water Boars are traditional, regional water authorities charged with managing water barriers, waterways, water levels, water quality and sewage treatment in their respective regions.

option is only used during dry spells in the summer, as the quality of the Rhine water is much lower than that of the seepage water, and its intake has detrimental effects on the water quality in the Bethune polder.

Water Quality Challenges

As the water quality from the two sources is very different, Waternet uses two different treatment procedures at separate treatment plants. The Bethune polder seepage water is pre-treated at the Loenderveen treatment plant by coagulation, primarily to remove phosphorus, and is then pumped into an artificial lake (Waterleidingplas), where it is stored for approximately 100 days. Coagulation is performed using iron chloride. Phosphorus removal is important to limit algal growth in the lake, thus preventing algal blooms. During retention in the lake, natural processes enhance the water quality, breaking down organic matter and ammonia. Water is then abstracted from the lake at 12m depth to minimize temperature fluctuations. After rapid sand filtration, the pre-treated water is transported to the Weesperkarspel plant through a 10km supply line. In this treatment plant, ozonation takes care of disinfection and the transformation of humic acids into more readily biodegradable organics. Ozone also destroys any organic micro-pollutants present in the water. The next treatment step is softening of the water through pellet softening. Finally, the water is filtered over biologically active carbon filters followed by filtration over slow sand filters, reducing the organic matter content and improving the biological stability of the water. The latter aspect is important, as Waternet, like all drinking water utilities in the Netherlands, supplies its drinking water without any residual disinfectant in the water. Low assimilable organic carbon content is an important aspect to prevent excessive growth of micro-organisms in the distribution network. The final step in the treatment of the seepage water is filtration over slow sand filters.

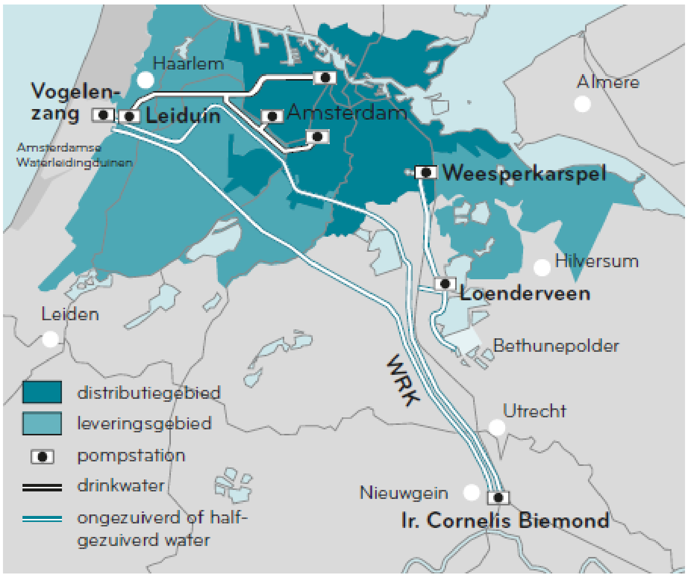

Figure 6-16 Waternet Water Abstraction,Ttransportation, and Treatment Locations and Waternet Drinking Water Supply Area (dark green) and the area supplied with Waternet Water Distributed by Other Water Companies (light green).

Water taken from the Amsterdam-Rhine Canal undergoes a very different treatment process. This water is of variable quality and contains higher concentrations of micro-organisms, micro-pollutants and nutrients. The raw water at the intake at the Nieuwegein intake station Ir. Cornelis Biemond is continuously monitored using an array of sensors, including both physical-chemical technologies as well as effect-based biomonitors. The intake can be stopped when water quality is compromised. At the intake station, the water undergoes the same pre-treatment steps as the seepage water: coagulation by addition of iron chloride followed by rapid sand filtration. After pre-treatment, the water is transported to sand dunes on the North Sea coast where it is infiltrated. The city of Amsterdam has been extracting drinking water from these dunes since 1853, and to stop over extraction which led to saltwater intrusion in the coastal aquifer, artificial recharge was started. From the infiltration ponds, the water filters through the dunes and in a retention time of 60-100 days, during which biological and physical adsorption processes clean up the water. The water is then extracted from open canals and transported to the Leiduin water treatment plant where it is aerated and then treated with the same procedures as the ground water: ozone, carbon filtration and slow sand filtration.

Approach and Implementation

Online water quality monitors at Waternet are in use for a number of purposes. At the surface water intake, water quality is monitored to ensure only water of sufficient quality is introduced in the treatment process. During water treatment, online measurements are used to ensure process performance and the quality of the water produced. Although sensors have been in use for many years, online control based on online water quality monitors has only been performed since 2007. Since then, however, the reliance on these online monitoring systems has taken a flight, and in 2013 Waternet started to move to ‘unmanned’ treatment operation; in this operational mode, the treatment plants at Nieuwegein, Loenen and Leiduin are operated remotely from one central control room at Weesperkarspel. The Weesperkarspel plant will be made ready for unmanned operation in 2014. The control room will be manned during office hours only. Outside office hours, the central control room will no longer be manned, with personnel on watch receiving a notification when an issue or upset occurs.

This development from decentralized (semi-)manual control at each individual treatment plant to centralized remote control of the treatment plants within the span of a few years has been driven by increasing pressure to improve the efficiency and economy of operations while at the same time maintaining the high quality of the drinking water. It has, however, been made possible by the preceding development and implementation of a robust quality assurance and quality control strategy for the online monitors which this unmanned operation relies on.

Evolution of the Monitoring Program and QA / QC Procedures for Online Monitors

Until the early 2000s, the use of water quality sensors at GWA (now Waternet) was not centrally organized. Online water quality monitors were used for process monitoring as well as research purposes, and each user was responsible for maintenance of his/her own instrument(s). As a result, a great diversity of sensors had been installed but maintenance was performed ad-hoc if at all. This led to unsatisfactory performance from the online instruments. Periodical verifications consistently showed the sensors were not performing well, leading to a lack of trust in their results from the process operators, who therefore relied on daily measurements with portable instruments instead of the online data for determining their process settings.

When in 2003 GWA merged with the Water Intake Station in Nieuwegein (up until then part of the independent organization Watertransportmaatschappij Rijn-Kennemerland, or WRK), a reorganization took place to absorb the additional activities and personnel. Contrary to GWA, the use of online sensors at WRK was well structured and managed by the water quality laboratory. The instruments performed well, were subject to a well-organized maintenance regime with periodical verification by an external laboratory. Due to the success of the approach taken, the online monitors were even included in the accreditation of all water quality analyses at the WRK by the Dutch national accreditation authority. This accreditation was a step taken in a drive for improved efficiency: it allowed a reduction in the reference analyses performed, thus reducing operational costs.

The difference in success between the two organizations became apparent due to the merger. As the costs associated with operating the sensors was substantial, the decision was made to review all use of water quality sensors. The goal of the review was to determine which instruments would be of benefit for operations and how the performance of these sensors and monitors could be brought up to a level where they could actually be used for process control. This task was assigned to the former head of the laboratory at WRK, who had developed and implemented WRK's successful strategy for using their online monitors.

The first step was a rationalization of the inventory, taking off line all systems whose data was not being used (e.g., NH_4^+ at the surface water intake). For all systems which remained in service, maintenance protocols were developed, and routine maintenance and quality assurance was put into practice. Due to the work involved in developing the procedures and getting them to be successfully accepted and embedded in the organization, including garnering the trust and support at all levels needed for the successful embedding of online monitoring in the organization, initially only one widely used measurement was tackled: pH. pH monitoring was to be used as a demonstration case, and the approach developed for pH was to be extrapolated to other sensors when proven to be successful.

The pH Example

The first step in developing a QA / QC procedure for all online pH sensors was to make visible the different approaches used. Furthermore, it was necessary to demonstrate that the successful approach as used at the WRK was not due to more time being used for maintenance but due to better systematics.

GWA

At GWA, pH sensors were being calibrated once per month. The daily manual readings, as analyzed in the lab, were used for process control purposes and to assess the correctness of the online instruments. Temperature effects on the pH were not taken into account.

WRK

At WRK, the pH sensors were verified bi-weekly using a buffer solution (pH = 8) (first-level control). The result from the verification were plotted in a Shewhart control card (Figure 6-17), in which each value is plotted in a graph which has the mean of the readings over a longer time period as a centre line. The control chart furthermore has upper and lower control levels drawn in, with the levels used at WRK being 2 standard deviations (2σ) and 3 standard deviations (3σ) around the mean. If the value measured during the verification was within the 3σ limits, no action was taken, and the instrument was returned to operation. Only when 2 subsequent readings fell between the 2σ and 3σ levels, or when an even a single reading fell outside of the 3σ levels, the instrument was recalibrated. In addition, a second-level control was performed by an external laboratory. Furthermore, all maintenance information was logged in a logbook.

In both cases, calibrations were performed using 2 pH buffers: pH 7 and pH 9. In the case of WRK, the calibration was verified by placing the sensor in a pH 8 buffer after calibration.

In the WRK approach, the calibration buffer were kept at a constant temperature throughout the year (18-22^o C) using a portable heating unit. This ensured that the sensors were always calibrated with buffers of the same temperature.

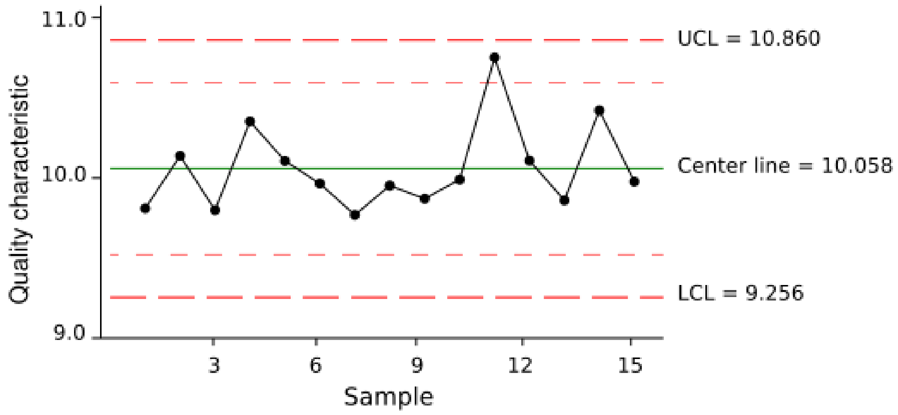

Figure 6-17 Example of a Shewhart Control Chart.

At first glance, the approach taken at WRK appears much more time-consuming. However, the constant conditions under which the sensors are verified and calibrated meant that calibration, the most time-consuming step, was performed less often and therefore the total time required per sensor was actually lower but performance was much better (accuracy of +/- 0.05 pH units achieved whereas with the GWA method +/- 0.1 pH unit accuracy could not be achieved). The explanation for the discrepancy was the following:

During verification, the difference between a reading from the instrument being verified and a reference instrument is evaluated. This difference depends on a number of factors, including measurement (in)precision of both instruments (the inherent uncertainty associated with all measurements), whether the instrument has reached temperature equilibrium in the buffer (otherwise the signal is not stable), but also the difference in temperature of the buffers used to calibrate the two instruments. The pH of a sample depends on the temperature. Despite the fact that most pH sensors include a temperature sensor and perform temperature compensation, this temperature compensation cancels out sensor internal temperature effects, however, it is not used by the sensor to correct for the actual change in pH in the medium due to the change in temperature. At GWA, the reference instrument was always calibrated in the laboratory (at a fairly constant temperature) but the field instruments were calibrated using buffers taken from the lab and at a temperature anywhere between lab temperature and outdoors temperature at the time of use. Two identical instruments measuring the same sample but calibrated at different temperatures will produce different results. This was what was occurring here: the field units were calibrated at a different temperature than the reference instrument, and this difference was not constant (depending on weather the time between leaving the lab and performing calibration) and unknown (not measured or logged). As a result, the difference between the verification instrument and the online instrument fluctuated wildly, suggesting the online instrument performed poorly, even though both instruments might have been working properly.

By calibration under well-defined and reproducible conditions, for both the online and the portable pH instruments, the variables during verification could be reduced to the performance of the online instrument. When this was done, the sensors used were found to perform rather well, and calibration frequencies were reduced.

In order to convince the operational staff that this approach was working and was actually more efficient, reducing maintenance load, the condition of each sensor was charted visually (status highlighted by colors, Figure 6-18) and the maintenance time required, both using the old and new methods, was logged. The results were evaluated monthly and shared with all personnel involved. The results were also discussed in monthly meetings with all personnel involved in sensor maintenance, meetings which were used to discuss experience and any issues encountered. By working together to implement the new QA / QC system and showing how it improved performance with, eventually, reduced effort, the approach gained the full support of the operators. Furthermore, the improving performance and the possibility to quickly check the status of a sensor in the monthly overview also led to growing confidence on the side of the process operators, who started to use online data to make process settings.

During the optimization and implementation period for the QA / QC system for the pH sensors, the following additional lessons were learnt:

- If an instrument is out of conformance, it is best to replace the electrode with a new (clean) electrode instead of recalibrating the affected electrode in the field. The old electrode is then taken to the laboratory for cleaning and regeneration, after which they can often be used again.
- The use of the pH 8 buffer for the first-level control was not optimal. Older sensors very briefly revived due to the high ionic strength of the buffer, leading to underestimation of the ageing effects of the sensor. Sensors would appear to be functioning properly only to fail shortly after performance verification, especially under cold conditions which exacerbate the effects of ageing of pH sensors. This was resolved by performing the first-level controls with a calibrated portable instrument instead of with a pH buffer.
- Calibration at prevailing temperatures in the process meant that, especially in winter, it took up to half an hour to reach temperature equilibrium in the calibration buffers. This was not only inefficient but also considered undesirable from a Health and Safety perspective. This instigated a change towards easily replaceable electrodes which can be pre-calibrated in the laboratory and then simply connected to sensor unit. This further standardizes calibration conditions as well as simplifying the maintenance work to be performed in the field. At present, all pH monitors in operation are of the electrode plug-in type.
- Despite standardized calibration procedures for all sensors, there remained a variable difference between measurements in the field (both from the online units and the portable sensors) and the second-level control measurements on samples analyzed by the external laboratory (Het Waterlaboratorium). This was tracked down to being caused by the fact that the laboratory measured the samples at room temperature, whereas the field measurements were taken under the prevailing water temperature. As with the calibration buffers, this resulted in a difference between the lab results and field results, the difference changing with the water temperature. To minimize this effect, the laboratory changed to measuring all samples for pH in a climate chamber at 12°C, the average annual water temperature. Furthermore, the lab results are now being corrected for the difference between the sample temperature measured in the laboratory and the temperature of the sample during sampling.
- The monthly reports on all sensors allow long-term performance evaluations and detection of bottlenecks; sensors with below-par performance can easily be recognized because they require more frequent calibration and are out of conformance more frequently. Such instruments can then be looked into, e.g., for installation issues or harsher operational conditions requiring more frequent QA / QC checks and/or maintenance. Also, the overviews allow identification of overall drop in performance both of the sensors but also by the maintenance teams. This has occurred a few times due to various reasons:
    - A change in purchasing strategy – centralization of purchasing led to reduced availability of spare parts, which showed up by increased out-of-conformance in the overviews. The purchasing strategy was rectified.

- Insufficient personnel due to holidays/illness led to reduced scores (negative score also incurred when an instrument was not checked on time). This information has been used in scheduling work and has also started a process of personnel exchange between the different treatment plants, so they can substitute when necessary.

- Reduction in the frequency of the second-level controls. Once the procedures were implemented, the added value of the second-level controls decreased. Their frequency was reduced from weekly to monthly. They are still seen as valuable as they verify the work done by the technical service, i.e., it keeps them on their toes.

Initially the new regime was trialed at one treatment station only (Weesperkarspel), but when it proved successful it was implemented for all pH sensors within the drinking water branch of the organization. This success helped overcome the skepticism within the organization regarding sensors, which lingered after the issues seen in the past.

Management rapportage funtioneren online kwaliteits monitoren: **Weesperkarspel**

	2009				2010				2011				2012				2013			
	1e kw	2e kw	3e kw	4e kw	1e kw	2e kw	3e kw	4e kw	1e kw	2e kw	3e kw	4e kw	1e kw	2e kw	3e kw	4e kw	1e kw	2e kw	3e kw	4e kw
Totaal indruk funtioneren monitoren	79	91	92	91	89	92	92	90	91	93	95	92	93	88	95	90	86	87	#####	#####
aantal monitoren	29	29	27	27	28	37	36	38	38	38	30	28	36	37	39	37	39	37		
	1e kw	2e kw	3e kw	4e kw	1e kw	2e kw	3e kw	4e kw	1e kw	2e kw	3e kw	4e kw	1e kw	2e kw	3e kw	4e kw	1e kw	2e kw	3e kw	4e kw
1. Zuurstof	70	87	90	80	83	93	94	93	83	97	93	100	93	90	97	73	97	80	#####	#####
2. Troebelheid	76	94	93	92	84	94	97	91	89	97	97	87	98	85	99	98	92	98	#####	#####
3. Zuurgraad	84	91	95	92	95	91	88	89	95	90	95	92	90	90	94	89	89	80	#####	#####
4. Temperatuur	67	100	100	100	83	83	100	100	100	100	100	100	100	88	83	100	100	100	#####	#####
5. Hardheid	87	88	84	85	86	89	80	78	80	79	85	84	87	72	89	78	76	83	#####	#####
6. Ozon in gas	79	68	83	74	100	100	#####	#####	100	94	95	61	70	92	100	96	89	#####	#####	#####

Figure 6-18 Example of the Visual Representation of Sensor Performance Used for Performance Evaluation.

Costs and Maintenance

Provide indicative information on required activities (staff-hours) and costs associated with acquisition and maintenance of the online water/wastewater quality monitoring instruments.

Data Handling

If applicable, describe how data is treated and transformed into useful information. E.g. in the case of early warning systems / water security applications describe how false positives are reduced, if and what software tools are used, how alarms are handled / which actions are taken in case of an alarm.

Evaluation of Successes and Limitations

Embedding the QA / QC Procedures in the Organization

The QA / QC approach has been embedded in the organization as follows:

- A directive detailing the steps to work through during performance verification and maintenance is available.
- The directive also defined the roles of the different departments within Waternet.
- The directive is issued by the Water Production department.
- The Water Production department acts as contracting agency. The technical department acts as contractor. This approach leads to a more businesslike relationship, leading to accountability. However, this is used mainly for evaluating purposes and does not lead to consequences in case of non-conformance. Issues are solved by co-operation between the two departments.
- Digital logbook, accessible through the intranet. Access:
    - Read: all, including process operators and managers.
    - Write: maintenance department.

This QA / QC approach has now also been implemented for the hardness analyzers, the turbidity sensors and the dissolved oxygen sensors used in the drinking water division of Waternet.

The total number of sensors and monitors this applies to across the WRK, Loenderveen, Weesperkarspel and Leiduin facilities and the associated maintenance efforts are summarized in the table below.

Table 6-8. Overview of Sensors in Use and Associated Maintenance Effort.

Parameter	No. of Instruments	Calibration		First level control		Maintenance		Second-level control
		n/year	hours per calibration	n/year	hours per control	n/year	hours per maintenance	n/year
pH	43	4	1	26	0.5	13	0.25	13
pH (high priority)	7	4	1	52	0.5	13	0.25	13
Turbidity	13 + 17	2 / 0*	1 / 0	13	0.25	26	0.25	0
Hardness	7	0	0	157**	0.25	52	1	52
Dissolved Oxygen (amperometric)	8	1	1		0	0	0	13
Dissolved Oxygen (optical)	4	0	0		0	6	1	13
Conductivity	4	2	0.5	4	0.5	0	0	13

*: calibrated by manufacturer once per year
**: 3x per week

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The total effort for maintenance and calibration for these sensors (including travelling time between sites and plants) amounts to 1.6 FTE.

Benefits

Through the standardization of rationalization of the instruments used and the maintenance procedures, the costs for instrument operation (excluding hardware costs for replacement instruments) has been reduced from 600,000 Euro/year to 400,000 Euro/year. Further reduction in costs is expected from a further reduction in second-level control measurements. It is expected this will be possible as a result of the excellent performance of the online monitors.

Whereas online monitors were viewed as unreliable and not trustworthy as recently as 2003, the first operational online control relying on sensor data was started in 2007. Currently, Waternet is in transition to 'unmanned' operation, with one central control room for all drinking water treatment plants and with this control only being manned during office hours. This leads to reduced operational costs for the treatment plants, as less personnel is needed to operate the plants. This unmanned approach is heavily reliant on the high-quality information coming from the online water quality monitors.

The water quality is more closely controlled:

- Savings in acid and caustic consumption (used in various stages in treatment)
- More constant Saturation Index (is an important quality indicator, as this affects scaling in pipes and (consumer) installations)
- More precisely controlled saturation index leads to less lime precipitation on carbon filters. This leads to longer run times and higher carbon regeneration efficiency.
- No more caustic peak when switching on a new carbon filter bed, therefore a more constant water quality.

Currently being added are UV sensors to provide control inputs for ozonation, helping determine the optimum ozone dose required to reach the target disinfection potential (Ct value). Differential UV absorption measurements provide direct information on the failure of ozonation (Figure 6-19).

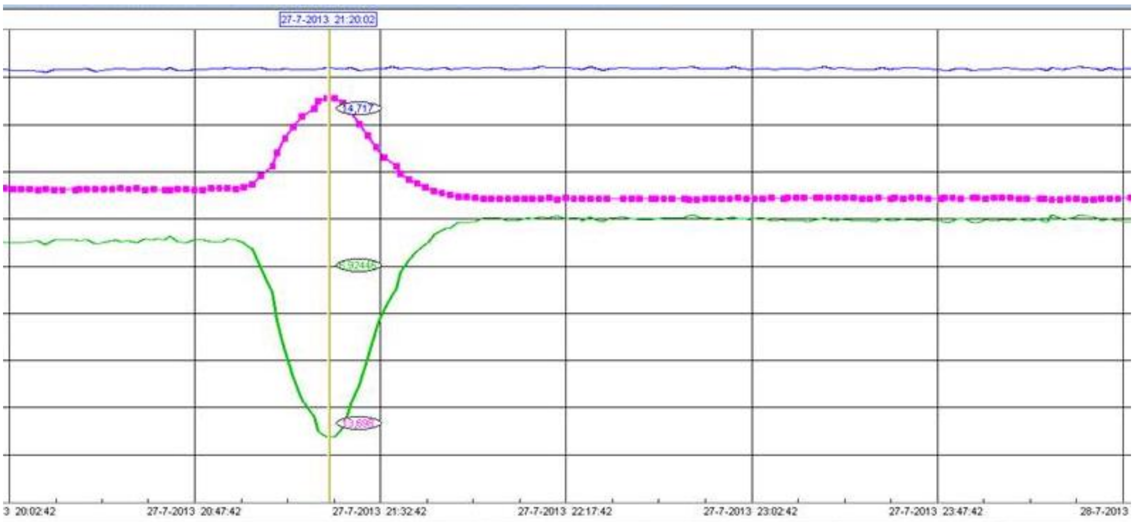

Figure 6-19 **Screenshot from Waternet SCADA Interface, Showing a Failure in Ozone Supply (green) and Coinciding Increase in the UV Parameter (blue) Indicating the Change in Absorption due to Ozonation Decrease. ΔUV is Related to the Amount of Organic Material that has Reacted with Ozone, and therefore an Indicator of the Amount of Ozone Dosed. The Failure Was Detected Based on ΔUV Before the Control Room Reported the Issue.**

Lessons Learnt

The following lessons can be learnt from the experience at Waternet:

- The successful application of sensors and monitors for control purposes requires a good QA / QC strategy, which includes procedures for sensor verification and maintenance. The strategy itself, however, is not sufficient. It needs to be embedded in and supported by all levels of the organization. Only with this support and the awareness at all levels of the importance and benefits of proper QA / QC as well as the value of the results obtained with the instrumentation, can the strategy be successfully executed and kept upright for an extended period.
- It is preferable to have fewer instruments which are maintained properly than to have a great number of poorly maintained sensors which nobody believes in.
- More intensive maintenance and performance verification will reduce the overall time spend on sensor maintenance, as the amount of unnecessary failures, calibration and maintenance is reduced. An overall cost reduction can be achieved while at the same time increasing data quality and up-time.
- When implementing such an extensive QA / QC strategy, a dedicated process manager is necessary, to keep the focus and to involve all relevant parts of the organization. Creating support for the approach can be a time-consuming and frustrating activity but is crucial for the success of the operation. Success can depend on the work of a few people within the organization.
- Even the most widely used parameter, pH, has a high complexity, and getting it right depends on many factors, which are often unrecognized.

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Source

Drinkwaterplan 2010-2014, Waternet