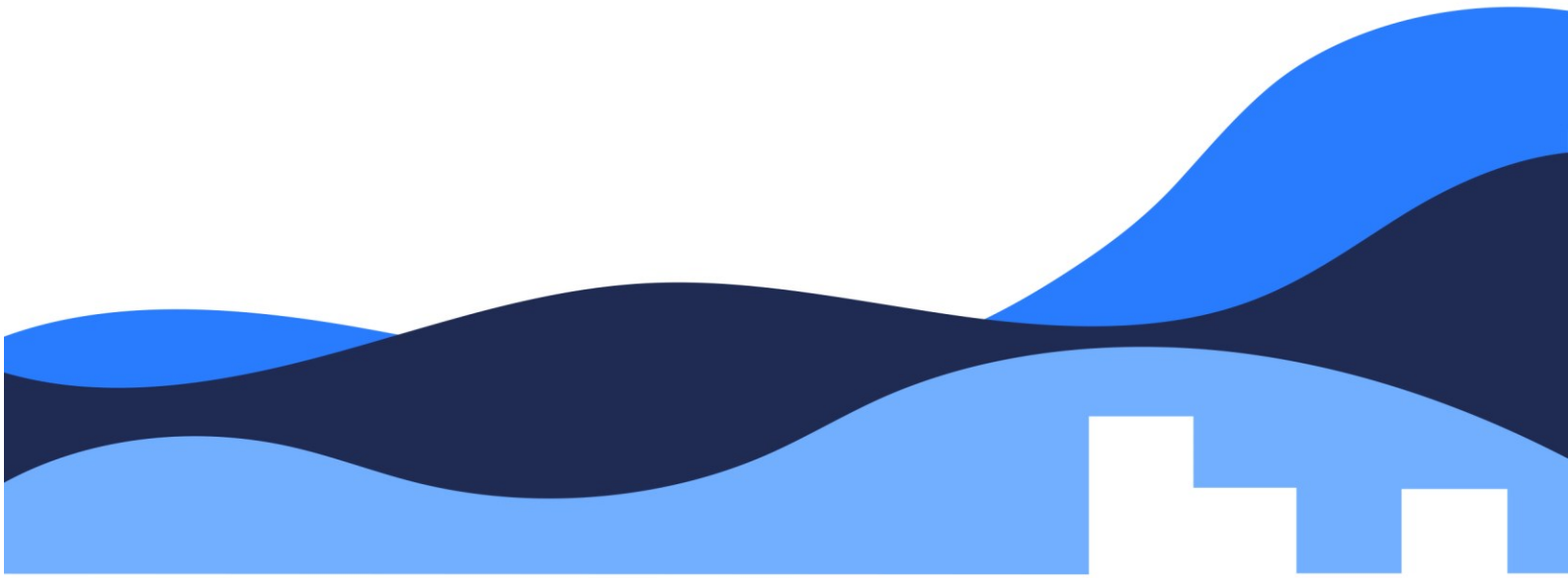
PRACTICAL MANUAL ON INNOVATIVE SENSOR INTEGRATION, VALIDATION AND OPERATION AND MAINTENANCE IN EXISTING WATER INFRASTRUCTURE

PUBLIC VERSION



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Deliverable N° 1.1	Practical manual on innovative sensor integration, validation and operation and maintenance in existing water infrastructure
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Author(s)	UNIVPM – FLUIDION – KWB – SIAAP – CAP– ISS
Contact for queries	Francesco Fatone (UNIVPM)
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Abstract	This deliverable reports on procedures for the management of a network of online real-time sensors and analyzers. It consists in a practical manual for innovative sensor integration, validation and operation and maintenance in existing water infrastructures. Finally, it provides an assessment of the accuracy of an innovative sensor for online faecal bacteria measurements, the ALERT System.

Dissemination level of the document

X	PU	Public
	PP	Restricted to other programme participants
	RE	Restricted to a group specified by the consortium
	CO	Confidential, only for members of the consortium

Versioning and contribution history

Version*	Date	Modified by	Modification reasons
D0	30/05/2020	UNIVPM	Draft full structure and partial detailed contents of chapters 1-4 for initial internal discussion
D1	24/07/2020	CAP	Add partial detailed contents to chapter 5
D2	21/08/2020	UNIVPM	Revision after discussion with coordinator KWB
D3	24/09/2020	CAP	Partial detailed contents added to chapters: – 4 – 5.1 – 5.2
D4	08/10/2020	FLUIDION	Add contents at chapters 4-5-6-7
D5	12/10/2020	SIAAP	Add contents at chapters 5-6-7
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D7	03/11/2020	UNIVPM	Add contents about data platform at Par. 2.6
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D9	06/11/2020	UNIVPM	Final revision and editing
D10	20/11/2020	All partners	Revision after internal review
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S2	04/03/2021	UNIVPM, FLUIDION	Integrated with monitor comments
R1	30/11/2021	All partners	Public version
S	30/11/2021	UNIVPM	Final editing

* The version convention of the deliverables is described in the Project Management Handbook (D7.1). *D* for draft, *R* for draft following internal review, *S* for submitted to the EC (under external review) and *V* for approved by the EC.

Note that previous version to *V* are draft since they are not yet approved by the EC.

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Table of content

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List of figures

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List of tables

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Glossary

API: Application Programming Interface

ARPA: Agenzia Regionale per la Protezione Ambientale

ASM: Activated Sludge Models

BOD: Biochemical Oxygen Demand

BSM: Benchmark Simulation Models

BWB: Berlin Water Utilities

BWD: Bathing Water Directive

CEC: Compound of Emerging Concern

CFU: Colony Forming Unit

CHP: Combined Heat and Power

COD: Chemical Oxygen Demand

CSO: Combined Sewer Overflow

D.Lgs: Decreto Legislativo

DO: Dissolved Oxygen

DS: Digital Solution

DSS: Decision Support System

DTS: Distributed Temperature Sensing

DWC: Digital-Water.City

E.coli: Escherichia Coli

EPA: Environmental Protection Agency

EU: European Regulation

EWS: Early Warning System

F:M: Food to Microorganisms ratio

GSE: Gas Selective Electrode

HRT: Hydraulic Retention Time

IA: Index of Agreement

ISO: International Organization for Standardization

IUWRS: Integrated Urban Wastewater and Reuse System

KPI: Key Performance Indicator

MMF: Moving Median Filter

MPN: Most Probable Number

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MUF: 4-methylumbelliferyl

MUG: 4-Methylumbelliferyl-β-D-Glucuronide

ONP: Ortho-Nitrophenol

ONPG: Ortho-Nitrophenyl-β-Galactoside

ORP: Oxygen Reduction Potential

PCA: Principal Component Analysis

PCP: personal care products

PFAS: poly- and perfluoroalkyl substances

SCADA: Supervisory Control And Data Acquisition

SWMM: Storm Water Management Model

TIC: Total Inorganic Carbon

TOC: Total Organic Carbon

TSAO: Two-Stage Advanced Oxidation Process

TSS: Total Suspended Solids

WHO: World Health Organization

WQIP: Water Quality Integrated Platform

WWTP: Wastewater Treatment Plant

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Executive summary

This report delivers a practical manual to support operators with the management of sensors networks in existing water infrastructures. It includes (1) the presentation and assessment of a new easy-to-use sensor for faecal bacteria measurements, (2) methodologies for the validation of online sensors and analysers and (3) best practices for installation, operation, and maintenance.

In DWC, raw data collected from on-line sensors and lab analyses are integrated and analysed to gather conclusive information and early warning to support decisions to deliver safe water reuse and inform about bathing water quality. Three relevant case studies, namely Paris, Berlin and Milan, were investigated in this research. In the case studies of Paris and Berlin, sensors were installed to monitor microbiological contamination in bathing water sites. In the case study of Milan, a real-time sensor network was designed to promote safe water reuse reducing the risk of microbial contamination of soils and crops during irrigation, while assuring compliance of wastewater quality with reuse standard limits.

The technical characteristics of all the installed on-line sensors are reported in **section 1**, including the innovative ALERT devices manufactured by FLUIDION, which allow the on-line measurements of faecal bacteria indicators. The section also describes in detail measurement characteristics, i.e., static and dynamic characteristics of instrumentation, operational modes, initial measurement accuracy and standards.

The use of real-time data to support health protection and risk management requires primary their validation, in terms of reliability, in order to integrate the standard lab measures with a continuous monitoring system, for control optimization and risk minimization. To date, one of the main lacks on risk management approach is the absence of common procedure on how to treat non-standardized data, such as real-time online data. To answer this question, this report intends to provide practical information about validation, operation and maintenance of on-line sensors for the three representative case studies. Particularly, this report includes

- Return of experience on installation, troubleshooting and maintenance (**section 2**).
- Data analysis and assessment of the bias, precision and accuracy of the online sensors (**section 3**).

The conclusions are reported in **section 4**.

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Note: the preparation of this report has been impacted by the COVID pandemics. In consequence, a previous draft version was delivered in November 2020. The present document represents the final report, and compared to the previous version it brings additional input regarding:

- Description of the ALERT System V2 (paragraph 1.1)
- The return on experience about installation, maintenance, and operation of the ALERT System V2 (paragraphs 2.1.6, 2.1.7, 2.2.3, 2.2.4, 2.3.6, 2.3.7, 2.4)
- The test of the ALERT System V2 and the assessment of the bias, precision and accuracy of the device in three case studies of Paris, Berlin and Milan (paragraphs 3.3.2, 3.3.4, 3.3.6, 3.3.7),
- A detailed assessment of the accuracy of the online sensors deployed at the Peschiera-Borromeo WWTP (Milan case-study) and a new methodology for outliers' detection from the acquired signals (paragraphs 3.2, 3.4).

In addition, the introductive sections of the deliverable have been revised, and redundant contents removed.

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1. Monitoring networks and sensors deployed in DWC

The project DWC aims to promote informed decision support and stakeholder engagement to reduce risks for human health and the environment in two defined contexts, which are bathing water sites and water reuse applications. Particularly, DWC intends to use the value of a large set of data obtained by employing on-line sensors for monitoring water quality in three selected case studies, which are located in Paris, Berlin and Milan.

The case studies of Paris and Berlin present the use of a smart network of real-time sensors for monitoring the impact of sanitation systems on the receiving bathing waters. On the other hand, in the case study of Milan, a smart network of real-time sensors is employed to build up an early warning system (EWS) to inform stakeholders about wastewater quality and related human-health risks, and to prevent microbial and toxic contamination linked to water reuse.

Bathing water and wastewater reuse for agricultural practices raise many concerns about the safety of the environment and human health. In these two contexts, a monitoring network represents a strategical control tool to ensure that quality standards for bathing water and treated wastewater are reached, and to minimize risks for human health.

In this chapter are reported the technical characteristics of all the on-line sensors deployed in the three case studies of DWC project. Particular attention is dedicated to the ALERT devises manufactured by FLUIDION, which represents the Digital Solution DS1 that has been developed for real-time and in-situ measurements of E.coli and enterococci. Finally, the remote control implemented in Milan for the management of the selected water reuse facility is briefly described.

1.1. Characteristics of ALERT devices for microbiological contamination monitoring

The ALERT line of instrumentation developed by Fluidion for monitoring microbiological contamination is a novel technology, which utilizes a modified real-time defined substrate method for bacterial enumeration. Fluidion ALERT technology allows fully-automated in-situ quantification of viable and cultivable generic E. coli and total coliforms. Alternatively, Fluidion ALERT technology can allow the quantification of the intestinal enterococci concentration or fecal coliform concentrations in both fresh water and seawater environments. The response time ranges between 2 and 12 hours (shorter response times corresponding to higher concentrations) and the limit of detection corresponds to 1 target bacterium in the sample volume of 25mL (i.e., a limit of detection of 4 bacteria/100mL in fresh water – this needs to be multiplied by the pre-dilution factor, if applied for specific protocols). The upper limit of measurement is 5×105 bacteria/100mL. Hence, the range of measurement covers five orders of magnitude in concentration. The detailed calibration and metrological validation results for fresh surface water E. coli enumeration have been published elsewhere (Angelescu et al., 2019; Angelescu and Hausot, 2019). The fact that no sample transport, conditioning, or preparation is necessary leads to logistic advantages, and eliminates the risk of sample degradation and human error. In addition, this technology produces rapid and reliable information on water quality to enable effective decision making in real-time. ALERT technology has been employed in numerous applications worldwide, which includes seawater monitoring, in-situ environmental monitoring of highly-polluted streams (Angelescu et al., 2018), pollution-source identification performed by regulatory agencies (Angelescu and Saison, 2020; Cronin et al., 2018; Loewenthal et al., 2018), monitoring campaigns accomplished in conjunction with remotely-controlled aquatic drones (Angelescu and Hausot, 2019). Recently, the ALERT technology has been applied to monitor E.coli concentration at different treatment points of a WWTP (Angelescu et al., 2020).

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Fluidion ALERT technology can be implemented in automated instruments capable of performing in-situ bacteria quantification. ALERT instruments can automate the full range of operations: sampling, reagent mixing, incubation, real-time multispectral optical analysis (absorbance/fluorescence), turbidity correction, signal analysis, bacterial quantification, wireless data transmission and automatic generation of notifications. ALERT technology can be employed in multiple configurations: ALERT System for performing automated in-situ bacterial enumeration to obtain time-series data at a target location; ALERT Lab as a portable device for rapid mapping of bacterial contamination at multiple sites, or as a bench-top device for rapid laboratory analysis (Figure 1). ALERT System can float like a buoy or be installed in a facility and can operate on battery, without an external power supply. The system can be remotely controlled from a cell phone or web interface and supplies data to the operator wirelessly. It is capable of carrying out seven measurements on a battery charge. The portable version (ALERT LAB) can be operated on rechargeable batteries at a remote field location or plugged into an electrical outlet, and it is capable of carrying out six measurements on a battery charge. Both ALERT System and ALERT Lab devices are employed in DWC.

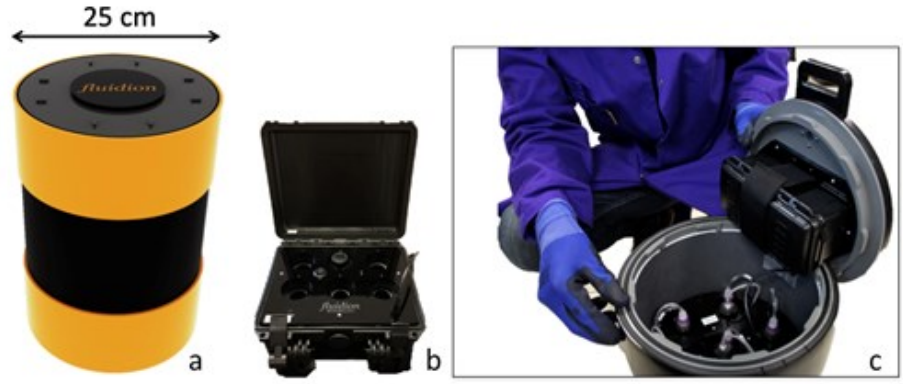

Figure 1: In situ ALERT System; b – ALERT Lab portable/bench-top instrument; c – View of the ALERT System during field maintenance operations (adapted from [Angelescu et al 2020b])

The bioreagent used in ALERT instruments contains a mixture of selective growth medium and 4-methylumbelliferyl-β-D-glucuronide (MUG), which can be hydrolyzed into fluorescent 4-methylumbelliferyl (MUF) by the β-glucuronidase enzyme present in E. coli bacteria (MUG is the standard substrate used in approved E. coli testing methods). The bioreagent used also contains ortho-nitrophenyl-β-galactoside (ONPG), another bacterial indicator that is metabolized by all types of coliforms in the sample and transformed into ortho-nitrophenol (ONP), resulting in development of yellow coloration. During the selective culture step (involving incubation at 37.0°C) bacterial metabolism progressively transforms MUG into MUF, generating broad fluorescence when excited at 385nm, with emission peaking around 460nm. Growth of non-target organisms is not promoted during the selective culture step, which makes the method highly selective to culturable E. coli, unlike rapid tests based solely on enzymatic activity without culture.

All ALERT instruments contain multiple individual bioreactors (six for the portable ALERT Lab, and seven for the in-situ ALERT System), each capable of independently incubating a sample and performing optical measurements using an optical sensor ring. The sensor ring contains three LEDs arranged to excite MUF fluorescence (385 nm excitation), measure ONP absorbance (430 nm) and compensate for sample turbidity (610 nm), as well as a photodiode coupled to a low-pass optical filter that blocks the UV excitation light.

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The fluorescence signal is measured at periodic intervals (every 5 minutes), with data transmitted in real time through the mobile phone network, to a remote cloud-based data server. The resulting curve (Figure 2) consists of an initial plateau, followed by sharp increase in fluorescence starting a few hours into the measurement. The curve is automatically analyzed by the data server to establish the fluorescence detection time, which is then used, after applying a specific calibration, to calculate the number of bacteria present in the original sample. Human quality control may still be required in <5% of the cases, but improvements in detection algorithm and automated QC checks should completely eliminate any type of human intervention in the near future.

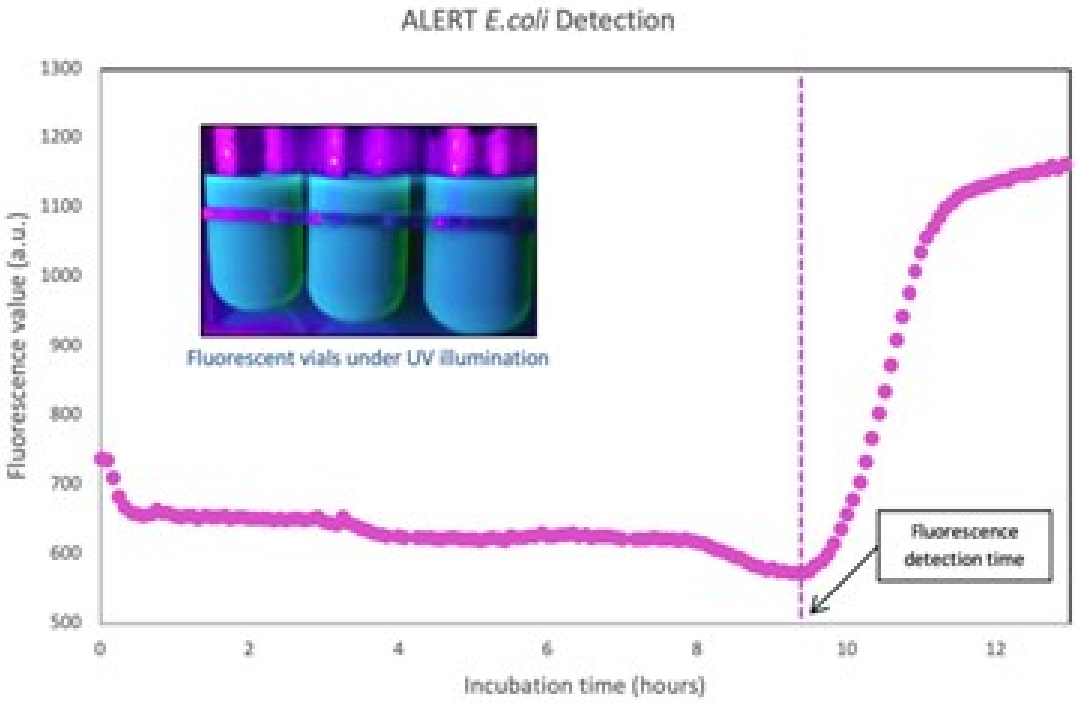

Figure 2: Typical fluorescence signal obtained from the ALERT device: an initial signal plateau is followed by sharp increase in fluorescence starting a few hours into the measurement. The fluorescence detection time is automatically interpreted by the cloud server and used for providing E. coli quantification. Inset: Photo of sample vials illuminated by UV light, after incubation. Adapted from Angelescu et al. (2020b)

Recently, but after the beginning of DWC project, FLUIDION has developed a new version of the Alert System, which is named as ALERT System V2 and that has been also tested in DWC case-studies. The ALERT System V2 (in short, ALERT V2) is a completely redesigned instrument, based on the same measurement technology as the ALERT LAB and ALERT System, but implementing a disposable cartridge system for measurements. Like the ALERT System, ALERT V2 contains seven bioreactors, and is thus capable of performing seven independent measurement cycles before new maintenances. However, instead of using internal sampling bottles, connected by tubes (which generates a complex maintenance due to deployments, involving cleaning and disinfecting all the hydraulic parts that have been in contact with the samples, such as the tubes, check valves, bottles and filters), the ALERT V2 integrates all the required components into a disposable cartridge which just needs replacement at the end of the 7-measurement cycle (Figure 3).

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Figure 3: The ALERT V2 instrument, including a zoom on the sampling cartridge, at left. The cartridges are inserted in the instrument from the bottom, theirs sampling check valves being immersed in the water body of interest. Regarding the cartridge, from top to bottom we can identify the vacuum sampling port and hydrophobic filter, the transparent reaction chamber, the diffuser and isolation check valve, the reagent chamber and the sampling check valve.

The disposable cartridge contains a sampling check valve, a reagent chamber where the sample mixes with the reagent, and a second isolation check valve followed by a diffuser that helps homogenizing the sample-reagent mixture. The sample measurement then proceeds in an integrated transparent reaction chamber where the sample is incubated and optical measurements (absorbance at two wavelengths, fluorescence) are performed periodically. Finally, at the top of the cartridge is located a hydrophobic filter that defines the maximum fill volume of the cartridge, and a vacuum port which is used to activate the sampling. The full maintenance cycle consists of changing the seven cartridges and replacing the rechargeable Li-Ion battery with a freshly charged one, and it can be accomplished in approximately 2 minutes in the field (excluding the time required to retrieve and reinstall the instrument, which is installation-dependent and could add 2 or 3 minutes to the total start-to-finish maintenance duration).

Contrary to the previous ALERT System, the ALERT V2 now contains an external sample temperature sensor, which allows it to modulate the incubation program accordingly, in order to ensure rapid heating to the incubation setpoint. Moreover, it also contains an external data port that allows the ALERT V2 to be connected to an external water quality probe or sensor, in order to monitor and log different parameters in real time, and perform adaptive sampling based on the measured values. For example, a turbidity or conductivity probe can be used to identify the start of local rain events, or an ammonium or dissolved oxygen sensor could indicate a fresh wastewater release in the proximity of the sensor, which represents an useful information that can be used to trigger a sampling event for E.coli.

The system can be installed either in rail configuration, attached to a fixed structure, or in floating configuration – these installation modes are shown in Figure 4 below.

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Figure 4: The different installation configurations for the ALERT V2: free-floating configuration (left), rail mount attached to fixed structure (middle). At right is shown the ALERT V2 as connected to an external sensor (in this case the Aqualabo turbidity sensor used in the 2021 Ablon deployment)

The external mechanical details of the instrument are identified on Figure 5 and Figure 6 below.

Figure 5: The external mechanical details of the ALERT V2 instrument. The sampling ports are located at the bottom of the instrument.

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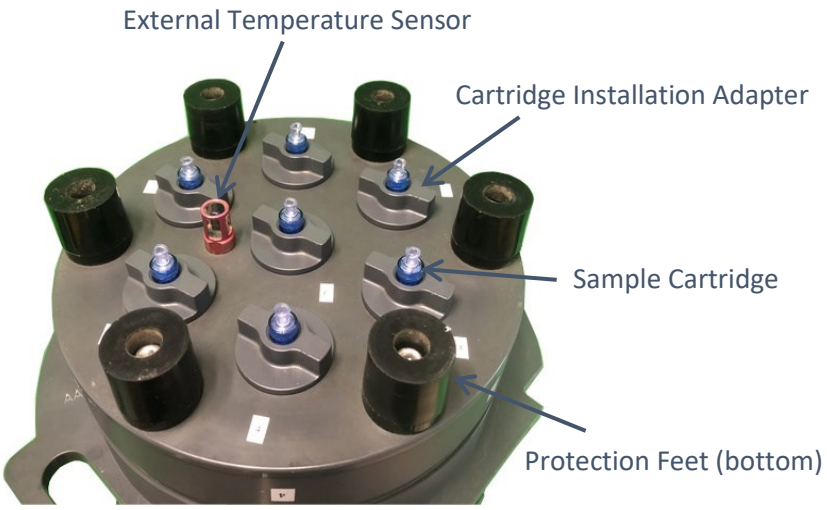

Figure 6: Upside-down view of the instrument's bottom interface, showing the protection feet, the seven cartridge sampling ports, and the external temperature sensor.

1.2. On-line sensors for water quality monitoring

In the case-studies of Paris and Milan, the installation of ALERT devices has been coupled with the use of additional on-line sensors for the monitoring of water quality. Particularly, in the Milan case-study many sensors and meters, alarms and automatic control tools have been applied. Indeed, in recent years, technological progresses allowed the digitalization of the wastewater sector providing new sensors, always more precise and reliable, and tools for decision support.

Below are reported the technical information related to all the on-line sensors for water quality monitoring deployed in case -studies of Paris and Milan.

1.2.1. On-line sensors deployed in Paris

Monitoring sites in the Paris case-study have been equipped with conductivity and/or turbidity sensors to control water quality.

The turbidity sensor manufactured by Ijinus works using a fiber optic IR technology and is able to transmit all the data using a Modbus RS-485 link. This specific sensor is built to be used in natural water as well as in the sewerage network.

The characteristics of the employed turbidity sensor are listed in

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Table 1:

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Table 1: Turbidity sensor characteristics

Measurement method	Fiber optic IR at 90°
Resolution	From 0.1 to 1 automatic according to the range
Measuring range	0 to 4000 NTU in 5 ranges: 0-50 NTU, 0-200 NTU, 0-1000 NTU, 0-4000 NTU Calibration: 0-500 mg/L range according to the norm NF EN 872 Range >500 mg/L according to the norm NF T 90 105 2
Functioning temperature	0°C to +50°C
Accuracy	< 5% from the NTU reading
Storage temperature	-10°C to +60°C
Response time	< 5s
Signal interface	Modbus RS-485
Rate of update measurement	Maximum < 1s
Battery	5 to 12 volts
Size	Diameter: 27mm, Length: 170mm without cable
Weight	300g
Material	PVC, PMMA, Polyamide
Maximum pressure	5 bars
Consummation	Standby: 40µA/ Heating time: 100mS/ Pulsing current: 500mA

The conductivity sensor employed in the measurement campaigns in Paris works using four electrodes (2 in graphite and 2 in platinum) and its characteristics are listed in Table 2:

Table 2: Conductivity sensor characteristics

Measurement method	Conductivity sensor with 4 electrodes
Resolution	From 0.01 to 1 according to the range
Measuring range	0-200,0 S/cm, 0-2000 µS/cm, 0,00-20,00 µS/cm, 0,0-200,0 µS/cm
Functioning temperature	0°C to +50°C
Accuracy	+/- 1% of the measured value
Storage temperature	-10°C to +60°C
Response time	< 5s
Signal interface	Modbus RS-485 and SDI-12 in option
Rate of update measurement	Maximum < 1s
Battery	5 to 12 volts
Size	Diameter: 27mm, Length: 177mm without cable
Weight	350g
Material	PVC, Inox
Maximum pressure	5 bars
Consummation	Standby: 25µA/ Pulsing current: 500mA

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An additional turbidity sensor, manufactured by AquaLabo, was integrated with the ALERT System V2. This turbidity sensor is able to send data every 5 minutes to the Fluidion server. In this way, turbidity measurements are always coupled to microbiological data to help data interpretation and elaboration. The sensor can measure turbidity values from 0 to 4000 NTU, using five different ranges and the nephelometric principle. Unfortunately, damage of this turbidity sensor occurred at the beginning of the installation of the Alert system V2.

1.2.2. On-line sensors deployed in Milan

On-line sensors for the monitoring of wastewater quality were installed at Peschiera Borromeo wastewater treatment plant (WWTP), which is located in the peri-urban area of Milan, and it is managed by CAP Holding water utility. This plant has been selected for the development of the Digital Solution DS3, planned in DWC to support decision on water reuse.

Peschiera Borromeo WWTP has a treatment capacity of about 566000 PE, and treats daily an average flow rate of 216000 m^3/d. The plant has two separated treatments trains (i.e., Line 1 and Line 2), which treat the wastewater coming from the two sewer network sectors of the peri-urban region of Milan. Line 1 includes coarse screening, pumping station, fine screening, grit and oil removal, primary sedimentation, biological treatment for organic carbon removal, tertiary filtration combined with nutrient removal in BIOFOR reactor and chemical disinfection with peracetic acid. Line 2 includes coarse screening, pumping station, fine screening, a compact SEDIPAC unit for grit and oil removal coupled with primary sedimentation, a BIOFOR unit for organic and nutrient loads removal combined with tertiary filtration and a final disinfection treatment with UV.

Within DWC project, Line 2 of Peschiera-Borromeo WWTP was selected for the development of digital solutions. This line of the plant was already equipped with a conventional network of sensors for monitoring the effluent wastewater quality. The set of sensors included flowrates, total suspended solids (TSS), ammonia (NH_4), nitrates (NO_3) and phosphates (PO_4), as well as sensors for biologic process monitoring, including temperature, Redox, NO_3 and dissolved oxygen. A sensor for measuring UV transmittance was also installed in the disinfection unit.

During DWC project, new sensors for pH, ORP, conductivity, TSS, NH_4, PO_4 have been installed before the primary treatments to monitor the influent wastewater quality. Additional probes for measuring conductivity, pH, total organic carbon (TOC) and UV absorbance at 254 nm were installed after the disinfection unit.

Figure 7 shows Peschiera Borromeo WWTP scheme and the localization of the sensors installed.

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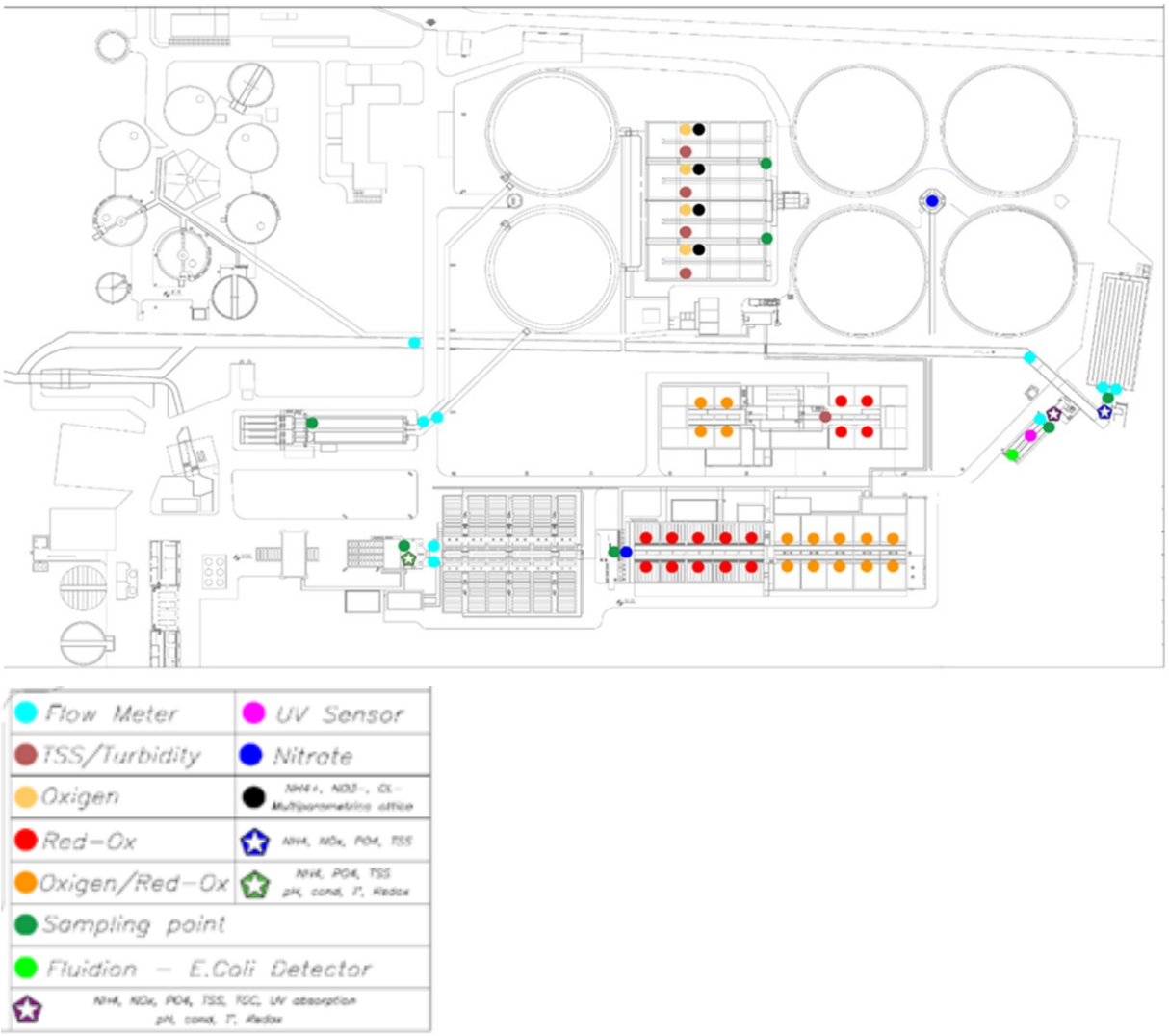

Figure 7: Sensors installed at Peschiera Borromeo WWTP

In the following paragraphs, technical information about sensors installed at Peschiera Borromeo WWTP are reported.

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Ammonium analyser- AMTAX sc

AMTAX sc is an online analyser of NH4-N and NH4 in water. The measure is performed through a gas selective electrode (GSE) that uses liquid to gas- phase conversion. The analyser is equipped with an autonomous system for automatic self-calibration and cleaning. Instrumentation includes a humidity sensor to detect leakage and automatically initiate a safe shutdown.

The probe is also provided with self-diagnostic routines with predictive analysis since it is able to give alerts if maintenance operations are necessary by monitoring the instrument's internal components and tracking service requirements.

The analyser can also remotely monitor sensors on any browser-enabled device.

AMTAX sc was already placed after the UV treatment and it was also installed upstream of the SEDIPAC unit. Amtax characteristics are shown in Table 3.

Table 3: Amtax sc characteristics

Measurement method	GSE (Gas Selective Electrode)
Measuring range	0.05 - 20.0 mg/L NH_4-N
Detection limit	0.05 mg/L NH_4–N
Accuracy	3 % + 0.05 mg/L, using standard solutions
Reproducibility	2 % + 0.05 mg/L
Response time	< 5 min
Measuring interval	5 - 120 min, adjustable per 5 min.
pH range	5 - 9 pH
Pressure range	-30 - 50 mbar with continuous sample preparation; at overflow vessel
Permissible Chloride range	Max. Cl^- concentration: 1000 mg/L
Operating conditions	-20 - 45 °C; 95 % relative humidity, non-condensing
Sample temperature	4 - 40 °C
Sample quality	Ultra-filtrated or comparable
Flow	1 - 20 L/h sample
Maintenance frequency	1/3 months (visual check cleaning solution, filter pads, analytical compartment, electrode); 1/year (electrode and cleaning pump checking); 1/year (replacing pump head and reagent pump); 1/ 2 years (switchable compressor)
Chemical consumption	reagent (2.5 l/3 months), standards (1-10 ml/3 months), cleaning and calibration (250 ml/3 months), electrolyte and membrane cap (11 ml/3 months)
Lifetime	~ 4-5 years

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Phosphate analyser - Phosphax sc

Phosphax sc is an analyser for the online measurement of ortho-phosphate in water. The measurement principle is based on molybdovanadate yellow colorimetric method. The analyser performs a zero-point calibration automatically without the use of standard solution.

Accuracy is maintained by compensating for background colour of the sample at the beginning of every measurement cycle.

A self- cleaning process is performed automatically. The analyser is equipped with humidity sensor to detect leakage and automatically initiate a safe shutdown. It also includes self-diagnostic routines with predictive diagnostics, which produces alerts for upcoming maintenance tasks by monitoring the instrument's internal components and tracking service requirements. It includes the capability to connect the device to a laboratory spectrophotometer to correct process measurements based on lab samples, without having to remove the process sensor from the water.

Phosphax sc is already located in the WWTP after the UV treatment and recently it has been installed before the SEDIPAC unit. Technical characteristics of the instrument are shown in Table 4.

Table 4: Phosphax sc characteristics

Measurement method	Photometric method using vanadate-molybdate
Measuring range	0.05 - 15.0 mg/L PO4-P
Detection limit	0.05 mg/L PO4-P
Accuracy	± 2 % ± 0.05 mg/L, with standard solutions
Reproducibility	± 2 % ± 0.05 mg/L
Response time	< 5 min
Measuring interval	5 - 120 min (fixed values selectable)
Permissible pH value of the sample	5 to 9
Sample pressure	With continuous sample preparation –30 mbar to +50 mbar at overflow vessel
Permissible chloride range	1000 mg/L Cl–
Operating temperature	–20 to 45 °C (–4 to 113 °F); 95 % relative humidity, non-condensing
Sample temperature	+4 to +45 °C (39 to 113 °F)
Sample flow	Range: 1.0 - 20.0 L/h
Sample quality	Ultra filtrated or comparable
Maintenance frequency	1/3 months (visual check measurement chamber, analytical compartment, filter pads, cleaning solutions), 1/year (check reagent pump, replace pump head)
Chemical consumption	reagent (2 l/4 months), cleaning solution (1 l/y)
Lifetime	~ 4-5 years

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Nitrate analyser - Nitratax sc

Nitratax sc is a process sensor for continuous measurement of nitrate in water. The measurement method uses ultraviolet (UV) light absorption below 250 nm. The probe has a two-beam absorption photometer that compensate interferences by turbidity and organic matter. The integrated cleaning system uses wiper technology. The sensor can be also installed in media with Suspended Solid contents.

The instrument has predictive diagnostics, giving alerts for upcoming maintenance tasks by monitoring the instrument's internal components and tracking service requirements. It includes the capability to remotely monitor sensors on any browser-enabled device.

Nitratax sc is already located after the UV treatment and it is not planned any other installation upstream.

Technical characteristics of the instrument are shown in Table 5.

Table 5: Nitratax sc characteristics

Measurement method	UV absorption measurement (unique 2-beam technique)
Measuring range	0 - 200 mg/L NO3
Detection limit	Using standard solutions: 0.1 mg/L NO2+3-N
Accuracy	± 3 % of measured value +0.5 mg/L, for standard solutions
Reproducibility	0.1 mg/L
Response time	1 min
Measuring interval	≥ 15 s to 30 min (fixed values selectable)
Functional verification	Using standard solutions
Operating temperature range	2 - 40 °C
Pressure range	≤ 0.5 bar
Maintenance frequency	1/week (calibration, visual inspection), 1/month (routine), 1/6 months (inspection), 1/year (seal change)
Lifetime	~ 6-7 years

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Turbidity and Suspended Solids probe - Solitax ts-line sc

Solitax ts-line sc is a probe for continuous monitoring of turbidity and/or suspended solids. The measuring principle consists in a dual-beam infrared/scattered light photometer (turbidity measurement in accordance with DIN ISO EN 27027, Total Suspended Solids (TSS) measurement equivalent to DIN 38414).

The sensor is factory calibrated and needs no calibration prior to use. It allows for individual calibration up to 5 calibration points.

The sensor has predictive diagnostics capability, which produces alerts for upcoming maintenance tasks by monitoring the instrument's internal components and tracking service requirements. It includes the capability to monitor sensors on any browser-enabled device remotely.

Solitax ts-line sc is already placed after the UV treatment and lately upstream of the SEDIPAC unit.

Technical characteristics of the instrument are shown in Table 6.

Table 6: Solitax sc characteristics

Units turbidity	NTU, FNU, or TE/F
Units TSS	g/L, mg/L, ppm, or % solids
Measuring range turbidity	0.001 - 4000 NTU
Measuring range TSS	0.001 - 50 g/L / 0.001 - 50,000 mg/L
Accuracy for turbidity up to 1000 NTU	< 5 % of measured value ±0.01 NTU, without calibration; < 1% of measured value ±0.01 NTU, with calibration
Repeatability for turbidity meaesure	< 1 %
Repeatability for TSS meaesure	< 3 %
Response time	1 - 300 s adjustable
Measuring interval	≥ 15 s to 30 min (fixed values selectable)
Maintenance required (typical)	1 h/month
Calibration method for turbidity	Formazin or Stablcal Standard (at 800 NTU).
Calibration method for TSS	Sample specific, based on gravimetric TSS analysis with a correction factor procedure
Operating temperature range	0 - 40 °C
Pressure range	PVC: 1 bar or 10 m; Stainless steel insertion sensor: 6 bar or 60 m
Maintenance frequency	1/month (visual inspection, check calibration), 1/6 months (inspection), 1/2 year (seal change)
Lifetime	~ 6-7 years

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pH and Temperature analyser – pHD sc

The sensor uses the differential Electrode pHD Measurement Technique, which employs three electrodes instead of the two electrodes used in conventional pH sensors, resulting in an improved measurement accuracy, reliability, and less downtime and maintenance.

The double junction salt bridge creates a barrier to contamination, which minimizes the dilution of the internal standard cell solution, thus leading to low maintenance needs. Furthermore, the replaceable salt bridge holds a remarkable volume of buffer to improve the working life of the sensor that guarantees the protection of the electrode. This sensor is also equipped with a NTC 300 Ω thermistor, which enables automatic temperature compensation while acting as a temperature analyzer.

This instrument is connected with Hach's innovative Water Intelligence System, which enables the remote visualization and management of the real-time measurements.

The sensor has been installed before the SEDIPAC unit, and downstream the UV treatment.

Technical characteristics of the instrument are shown in Table 7.

Table 7: pHD sc characteristics

Measurement method	Differential Electrode pHD Measurement Technique
Measuring range pH	0-14 pH
Measuring range T	-5 °C – 75 °C
Accuracy pH	± 0.02
Repeatability pH	± 0.05
Sensitivity pH	± 0.01
Accuracy Temperature	± 0.5 °C
Response Time pH	< 5 s
Response time T	< 2 min
Operating temperature range	-20 °C – 50 °C
Operating pressure range	< 2 bars
Operating flow velocity	< 3 m/s
Calibration	Two point automatic, one point automatic, two point manual, one point manual
Maintenance frequency	1/ 3 months (cleaning), 1/3 months (visual inspection), 1/year (salt bridge substitution)
Lifetime	~ 4-5 years

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Redox and pH analyser – pHD sc

The sensor uses the differential Electrode pHD Measurement Technique, which employs three electrodes instead of the two electrodes used in conventional pH sensors, resulting in an improved measurement accuracy, reliability, and less downtime and maintenance.

The double junction salt bridge creates a barrier to contamination, which minimizes the dilution of the internal standard cell solution, thus leading to low maintenance needs. Furthermore, the replaceable salt bridge holds a remarkable volume of buffer to improve the working life of the sensor that guarantees the protection of the electrode. This sensor is also equipped with a NTC 300 Ω thermistor, which enables automatic temperature compensation while acting as a temperature analyzer.

This instrument is connected with Hach's innovative Water Intelligence System, which enables the remote visualization and management of the real-time measurements.

The sensor has been installed before the SEDIPAC unit, and downstream the UV treatment.

Technical characteristics of the instrument are shown in Table 8.

Table 8: Redox pHD sc characteristics

Measurement method	Differential Electrode pHD Measurement Technique
Measuring range ORP	-1500 – 1500 mV
Measuring range T	-5 °C – 70 °C
Accuracy	± 0.02
Repeatability	± 0.05
Sensitivity	± 0.01
Accuracy Temperature	± 0.5 °C
Response Time ORP	< 5 s
Response time T	< 2 min
Operating temperature range	-20 °C – 50 °C
Operating pressure range	6,9 bars
Operating flow velocity	< 3 m/s
Calibration	Two point automatic, one point automatic, two point manual, one point manual
Maintenance frequency	1/ 3 months (cleaning), 1/3 months (visual inspection), 1/year (salt bridge substitution)
Lifetime	~ 4-5 years

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Conductivity analyser – 3798-S sc

The 3798-S probe employs an inductive measurement procedure without direct contact with the sample. Therefore, it is particularly suitable for dirty samples, such as wastewater. The probe is factory calibrated, ready for use and remains stable even after several months of use. It is equipped with digital data transmission technology common to all SC probes from HACH LANGE. This instrument is connected with HACH's innovative Water Intelligence System, which enables the remote visualization and management of the real-time measurements. It has been installed before the SEDIPAC unit and downstream of the UV treatment. Technical characteristics of the instrument are shown in Table 9.

Table 9: 3798-S sc characteristics

Measurement method	Inductive with integrated PT100 temperature sensor
Measuring range	250 µS/cm – 2,5 S/cm
Accuracy	±1% of actual value or ±0.004 mS/cm
Reproducibility	<0.2%
Accuracy Temperature	±0.2 °C
Response Time	< 2 m/s
Operating temperature range	-20 °C – 50 °C
Operating pressure range	< 2 bars
Operating flow velocity	< 4 m/s
Maintenance interval	2 years or after 1000 hours change of sealing
Calibration	Zero value calibration in air. 1-point calibration with defined resistance or with standard solution
Maintenance frequency	1/ 3 months (cleaning), 1/3 months (visual inspection)
Lifetime	6-7 years

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Organic load analyser – UVAS Plus sc

UVAS Plus sc allows the reagent-free continuous measurement of the organic load via the spectral absorption coefficient (SAC) at 254 nm. The values are instantly available due to the direct UV measurement.

This instrument is connected with HACH's innovative Water Intelligence System, which enables the remote visualization and management of the real-time measurements.

UVAS Plus sc has been installed only at the outlet following the UV treatment. Technical characteristics of the instrument are shown in Table 10.

Table 10 UVAS Plus sc characteristics

Measurement method	Measurement of 2-beam UV absorption without chemical reagents of the coefficient spectral absorption 254 nm in accordance with the standard
Measuring range	0.1 m^{-1} – 600 m^{-1}
Accuracy	1 % of measuring range end value within a measuring range from 50 to 100%
Calibration	Can be calibrated on COD and TOC parameters
Response Time	1 min
Operating temperature range	2 – 40 °C
Operating pressure range	0.5 bar
Operating flow rate	0.5 – 10 l/h (in the bypass)
Maintenance interval	1h per month
Maintenance frequency	1/ week (visual inspection), 1/6 months (inspection), 1/year (seal change), 1/week (check calibration through comparative measurements)
Lifetime	~ 6-7 years

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TOC analyser - BioTector B3500e

BioTector B3500is the sensor for the measurement of total organic carbon (TOC). At first, the device evaluates the Total Inorganic Carbon (TIC) present in the sample by acidifying the sample. Afterward, the patented two-stage advanced oxidation process (TSAO) with hydroxyl radicals generated in the analyzer by combining ozone with sodium hydroxide ensures the complete oxidation. Finally, the infrared CO2 measurement is achieved, and the TOC is then evaluated.

The B3500e comes with a built-in self-cleaning sample tube and reactor. Therefore, the analyzer requires maintenance only twice a year for standard items like pump tube replacement and calibration.

Data are easily accessible thanks to the remote access functionality to the BioTector network control unit (NCU).

BioTector B3500e has been installed downstream the UV treatment, and, although its installation has been time spending, it is now operational.

Technical characteristics of the instrument are shown in Table 11.

Table 11: BioTector B3500 characteristics

Measurement method	Infrared measurements of CO_2 following two-stage advanced oxidation with hydroxyl radical
Measuring range	0 – 250 mg C/L
Repeatability	± 0.45 mg C/L
Calibration	Automatic with Self-Cleaning Technology
Response Time	7 min 30 s
Storage capacity	9,999 data and 99 fault events
Operating temperature range	2 – 60 °C
Operating humidity	5 – 85 % (non-condensing)
Particle size	Up to 100 □m
Power requirements (Hz)	50 – 60 Hz
Power requirements (Voltage)	115 V AC
Maintenance frequency	1/week (air supply, reagent and sample pump check), 1/6 months (replenish reagent), 1/6 months (replacing the pump tube), 1/6 months (calibration)
Lifetime	~ 4-5 years

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1.3. Remote Control system in the water-reuse facility of Milan

The digital management of Peschiera Borromeo WWTP is performed by a remote control and a SCADA system for the continuous acquisition of online data measured at the WWTP. Laboratory analyses are also performed periodically for influent and effluent characterization to control specific processes. Data from laboratory analyses are uploaded and managed by specific software (e.g., WaterLims). The datasets of process parameters are managed in SCADA system. Equipment status and related alarms on electro-mechanical units are continuously monitored. It allows rapid intervention in case of anomalies detection. Offline data about cumulative energy consumptions, chemicals supply, sludge and waste production and disposal are stored in internal management systems. Maintenance operations, internal report and emergency procedures follow specific and documented protocols.

Since Line 2 was selected for the experimental activities in DWC project, below is reported a synthetic description of the main operational controls and management systems installed in Line 2.

Screening and pumping units are equipped with level radars, and alarms in case of malfunction of the electromechanical equipment. Energy meters are installed to measure dynamically the real energy consumption.

Sensors for pH, ORP, conductivity, TSS, NH_4, PO_4 are installed before the SEDIPAC unit, which is also provided with flow meters. All the equipment for sludge extraction, oil removal system and sludge conveyor are equipped with alarms. Energy meters measure the electricity consumption. On the internal back-flush, that is sent back to the SEDIPAC, chemicals are dosed for phosphorus precipitation, and the related electromechanical equipment is provided with alarms.

BIOFOR reactor for biologic and nutrient removal combined with filtration is divided into 10 modules, 5 dedicated to pre-denitrification and 5 voted to organic removal and nitrification. In the aerobic compartments REDOX, Temperature and Dissolved Oxygen are measured online with sensors, while the anoxic zones are provided with REDOX probes. In the internal recycle a $N\text{-}NO_3$ analyser is installed and the recycle flow rate is also measured. Backwashing is monitored with a flow meter, the flux is activated alternatively by temporization or by pressure signals from sensors installed on the filters surface. Energy meters are installed to monitor electricity demand.

In the UV disinfection unit, sensors are installed to monitor the UV light intensity. Maintenance operations are supported by a counter system with a threshold of maximum 10000 working hours for each lamp. Specific energy meters are installed to monitor UV unit.

In the final effluent, a set of probes are installed to monitor in real time several parameters and a flow meter is installed to control the amount of treated water discharged.

Energy consumptions is correlated with market costs on the platforms GME, EEX and Idex to analyze daily variations. Key Performance Indicators (KPIs) are automatically calculated and correlated with historical data to detect anomalies.

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Table 12 and

Table 13 describe the on-line and off-line measurements that can be accomplished at Peschiera Borromeo WWTP.

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Table 12: Online data available from the monitoring network installed at Peschiera Borromeo WWTP

Type	**Source**
Sensors: pH, redox, OD, conductivity, turbidity/TSS, ammonia, nitrate, temperature, ORP, UV transmission, TOC	SCADA. Sensors data of WWTP available in CAP control room. Data will be exposed by REST services or MQTT broker.
Flow meters: Q influent, Q bypassed, Q secondary treatments, Q backwash, Q effluent, Q biogas production	SCADA. Flow meters data of WWTP available in CAP control room. Data will be exposed by REST services or MQTT broker.
Energy meters	SCADA. Energy meters of WWTP available in CAP control room. Data will be exposed by REST services or MQTT
Energy production from solar / combined heat and power (CHP)	Data will be available in CAP control room.
UV dosage / intensity	Data will be available in CAP control room.
Alarms / radars connected to remote control	Data will be available in CAP control room.

Table 13: Offline data available from the monitoring network installed at Peschiera Borromeo WWTP

Type	**Source**
Design / process parameters	Internal procedures / SCADA
Laboratory analysis registered in RGFI (*registro giornaliero di funzionamento impianto - plant operational daily registry*)	Internal software (WATERLIMS)
Maintenance program and reports	Internal procedures
Absorbed power and working time of electromechanical equipment	Internal register
Energy bills	Internal register
Waste production	Internal register
Dosage solutions / chemicals	Internal register
Transports	Internal procedures

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2. Installation, maintenance and troubleshooting of on-line sensors

The feasibility and reliability of the installation, operation, and maintenance procedures represent a crucial aspect for assessing the performance of novel autonomous and remotely controllable sensors. Indeed, goals of the project addressed in this report are to provide:

- A new easy-to-use sensor for fecal bacteria measurements;
- Methodologies for the validation of online sensors and analyzers;
- Best practices for installation, operation, and maintenance.

In this Chapter, critical issues potentially affecting sensors reliability as well as inconveniences experienced in the different city case studies are reported with a special attention to ALERT technologies.

2.1. Demo-case in Paris: Surface water and storm-water study

As host of the Olympic and Paralympic Games, the city of Paris must ensure the opening of swimming sites for aquatic events. To make possible swimming activities in the city of Paris, and particularly in the Seine River and in the Marne River, the bathing water must be continuously monitored in order to evaluate its quality status. The main parameter to monitor in bathing water is the measurement of fecal indicator bacteria (FIB).

In order to evaluate the quality of water of the Seine River and of the Marne River, two different measurement campaigns were organized in several sites during wet and dry weather conditions. The first one was carried out during the summer of 2019 (from June to the beginning of October) using the auto-samplers and sensors of a provider (SEMERU) and the first version of the ALERT system developed by Fluidion. The second one took place during the summer of the year 2021 (In June and July) and the ALERT System V2 was installed in-situ while side-by-side weekly sampling was performed by the technicians working in the SIAAP laboratories.

In the following paragraphs are briefly described the sites selected for the experimental campaigns. Furthermore, the procedures required for the installation and maintenance of the monitoring probes are reported as well as all the difficulties encountered during the experimental tests.

2.1.1. Measurement sites

Figure 8 shows the four measurement points chosen for the experimental campaign in Paris. An important point to note here is that although the Marne River has bathing sites and discharges, it is also a tributary of the Seine River.

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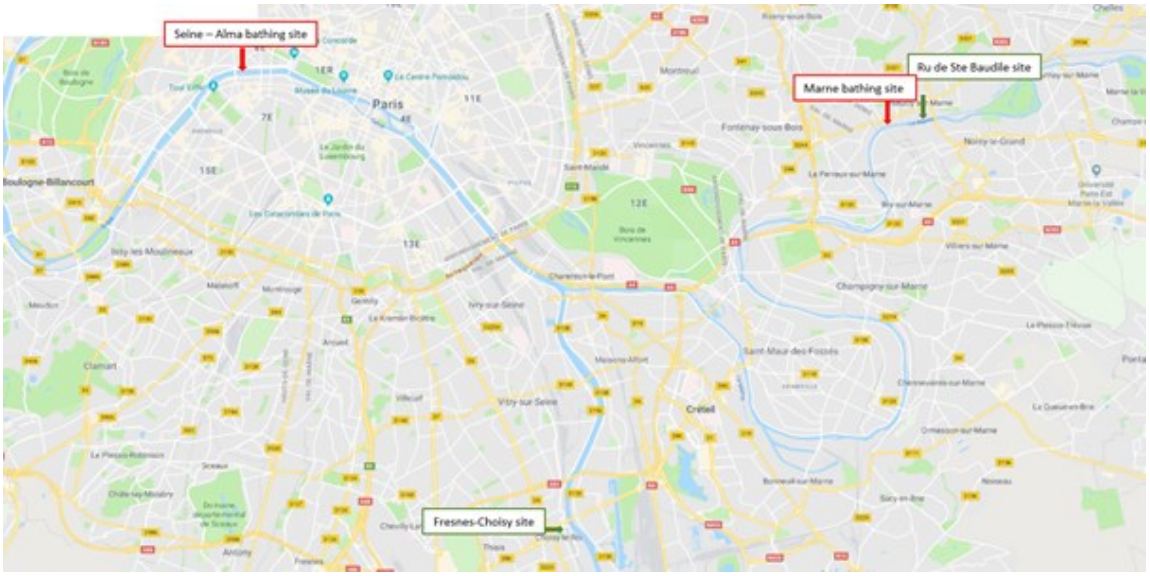

Figure 8: Map of the different sites of measurements for the 2019 campaign

Bathing site Seine - Alma

The monitoring site in the Seine River (i.e., Alma) is favorably located to monitor the composite pollution wave generated by the numerous discharges of rainwater runoff located upstream in the Seine and in the Marne River (Figure 9).

The Tarot floating public garden located upstream the Alma Bridge was selected as the monitoring site. This site is property of the City of Paris (Direction of Parks and Gardens) and offers controlled access (i.e., limited for public) with an electrical power supply.

Figure 9: Pictures of the Seine - Alma bathing site

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Marne bathing site

Concerning the Marne River, the technical objective was to study the dynamics of pollution caused by an isolated and nearby located discharge point for combined sewers overflow (Figure 10).

In this case, the Neuilly-Gagny anti-flood pumping station was selected as monitoring site, since it offers the following advantages: a closed room on the banks of the Marne River with an electrical power supply.

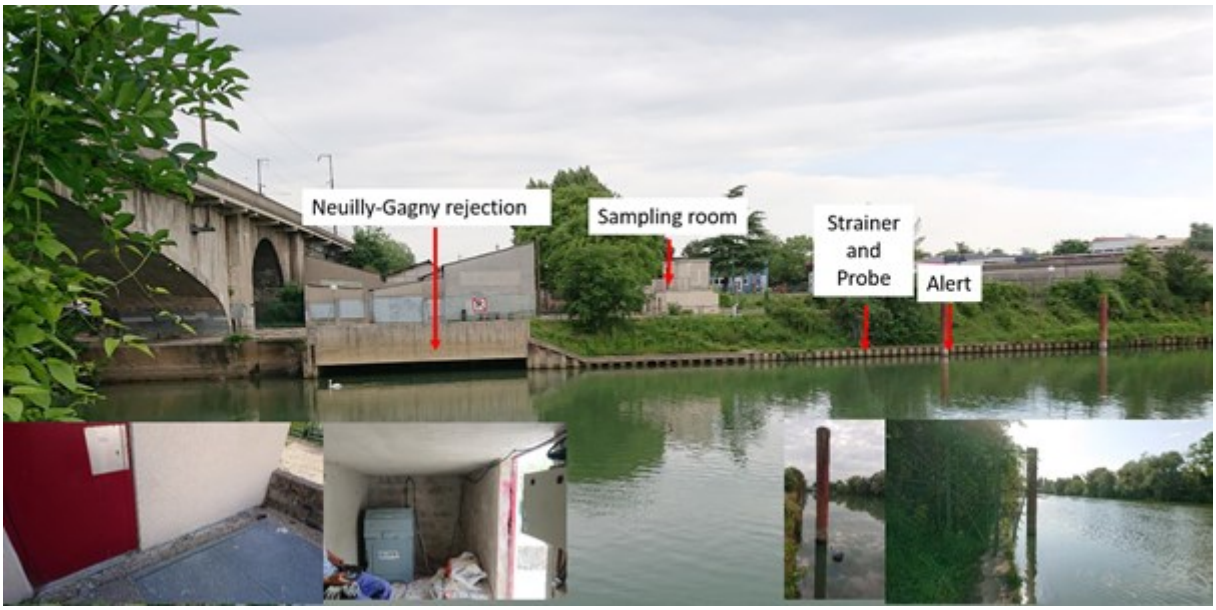

Figure 10: Images of the Marne sampling location

Saint Baudile site

The monitoring site is located at a significant rainwater runoff discharge in Neuilly-sur-Marne. However, the access to the measuring point was complicated due to the small diameter of the entry point. Thus, the access point was modified to make possible the installation of the needed equipment (Figure 11 and Figure 12).

Figure 11: Measuring point

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Figure 12: Saint Baudile Spillway

Fresnes-Choisy site

The last selected site in the Seine River (Figure 13) receives also major discharges of rainwater runoff, which could have significant influence on the quality of the water of the Seine River, and, particularly, at the Seine - Alma bathing site.

Figure 13: Picture of the installation of the samplers on the Fresnes-Choisy site

Ablon-sur-Seine site

One last measurement campaign took place during the summer of the year 2021, at a site upstream of Paris and of the largest wastewater plants in the area. The goal of this campaign was to retrieve additional data to calibrate the models that will be used for the prediction tool of the Early Warning System. It was also the occasion to test the ALERT System V2 developed by Fluidion and compare its results to the previous ALERT System (V1) that was used during the previous measurement campaigns.

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The site of Ablon-sur-Seine is located upstream of Paris as shown on the map in Figure 14. Particularly, it is located before the confluence with the Marne river and upstream of the Seine Valenton WWTP, which is the major cause of dry weather pollution events in the Seine river. This site is right downstream the confluence with the Orge river, which has a significant level of pollution, especially during rain events.

Figure 14: Ablon-sur-Seine site

In order to install the ALERT System V2, a secure location was required that was also easily accessible for maintenance, and for collecting the side-by-side samples for laboratory measurements (Figure 15). Those requirements were satisfied by the site of Ablon-sur-Seine, which is upstream of a dam where a lock is located to facilitate the passing of boats. In order to have a good representability of the water quality in the free-flowing part of the river, it was decided to place the ALERT System V2 outside the lock gates directly into the river and right before the dam, as shown in Figure 15.

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Figure 15: Alert installation at Ablon-sur-Seine site

The location where the ALERT System V2 was installed and where technicians collected the side-by-side samples was accessible only by authorized personnel and could be accessed through a small and secured bridge.

The campaign was originally supposed to take place during the months of July and August. However, due to maintenance work needed to take place during the month of August on the dam and the lock, it was decided to conduct the campaign earlier, during the months of June and July.

2.1.2. Installation and maintenance of on-line sensors and auto-samplers for water quality determination

The bathing sites in the Seine River (Seine-Alma) and in the Marne River have been equipped with sensors able to continuously measure conductivity and turbidity. The site of Saint Baudile was equipped with sensors for continuous turbidity measurement, while the site of Fresnes-Choisy was equipped with sensors for continuous conductivity and turbidity measurements.

Other conventional water quality parameters were measured through lab analysis to obtain a general frame of the water quality at the selected sites. The number and type of parameters measured are reported in

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Table 14.

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Table 14: Number of measurements made during the campaign

	Samples Seine - Marne Dry weather 24h	**Samples Seine - Marne Spatial variability**	**Samples Seine Marne Wet weather**	**Spillways Wet weather**
E. Coli	1	1	1	1
Enterococci	1	1	1	1
Turbidity	1	1	1	1
MES	1		1	1
BOD_5				1
DOC				1
COD	1	1	1	1
NH_4	1	1	1	1
NO_2	1	1	1	1
NO_3	1	1	1	1
PO_4	1	1	1	1
	9	**8**	**9**	**12**

The different measurements reported in

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Table 14 were conducted using the standards in Table 15. Those measurements were performed for samples collected both in Marne and Seine rivers, which are both affected by discharges of rainwater runoff (Fresnes-Choisy and St Baudile). Measurements were also performed during the spatial variability studies conducted in these two rivers.

The SIAAP laboratories, that performed physical-chemical and biological analyses, are located in Colombes, Noisy-Le-Grand, and in Valeton. The devices used for sampling were refrigerated samplers containing 24 vials with peristaltic pump. In order to carry out all the analysis (physic-chemical and biological), it was needed a total amount of 2.25 L for each sample. From this amount, 2 L were used for the physic-chemical analyses and 0.25L were used for the bacteriological analyses.

On the Ru Saint-Baudile, the maximum flow during rain events is usually reached after 30 minutes - 1 hour. Thus, the sampling frequency was generally set to 30 minutes, but the time step could change depending on the expected duration of the rains and the weather conditions. In contrast, the Fresnes-choisy is a site with a much larger watershed. As a result, the samples were taken every hour.

The river samplers were triggered remotely by means of a GPRS telecommunication box, allowing the control of a relay via SMS. The triggering signals were sent by the operator according to the information on the discharge rates at the Saint-Baudile site in the Marne River and at the Fresnes-Choisy site in the Seine River.

At the beginning of the sampling campaign, the probes were calibrated. Maintenance on samplers and probes was performed every week and consisted in probes cleaning and in checking that the samplers were still functioning properly.

During the campaign of 2021, the site of Ablon-sur-Seine was equipped with a turbidity sensor that was logged with the ALERT System V2. The integrated system was able to send data every 5 minutes and wirelessly to the Fluidion data servers.

It was decided that no auto-sampler would be used for this campaign. However, in order to provide the side-by-side laboratory *E.coli* measurements in parallel to the ALERT System V2 ones, technicians from the laboratories department of the SIAAP performed every Tuesday around 10 am a sampling collection, which was synchronized with the ALERT System V2 measurement.

The ALERT System V2 performed measurements of the *E. coli* bacteria and of Total coliforms. The side-by-side samples retrieved by the SIAAP technicians were analyzed for E. coli and intestinal enterococci bacteria, as well as NH_4 and TOC. The methods used for analysis are listed in Table 15.

Same as for the 2019 campaign, in 2021 both dry and wet weather data have been retrieved by the ALERT System V2. Daily samples were retrieved in dry weather. For the wet weather, the measurements needed to be synchronized to rain events, and multiple tools had to be used in order to make sure to get the event at the right time. Multiple weather websites and radar maps have been used to follow the rain events and define their beginning. In addition to that, the SIAAP's real-time remote control system and its rain events forecasting at different locations has been used. There were no predictions for the specific site, but fortunately there was a prediction available for a very close site (i.e., Athis Mons, upstream of Ablon-sur-Seine). The flowrates of different structures, such as the Orge river (affluent of the Seine River located upstream of the site) or specific stormflows not far from the site, were also used. The increase of these flowrates confirmed the hydrological impact of the rain event.

The combination of all these tools allowed the approximate identification of the beginning of the hydrological impacts of the rain event, that was then followed for the subsequent 48 hours.

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Considering that seven cartridges are available on the ALERT System V2, measurements were performed every six hours.

The summer of 2021 was unusual, since an unusually large number of rain events occurred, making dry weather periods very rare. Fortunately, the sunny weather appeared during a week in July, and it was decided to perform round-the-clock (24h) sampling at 3 hours intervals, instead of the usual daily sample. Sampling organization was therefore adapted to have enough data in dry weather to compare with wet weather, to have a full understanding of how water quality may be affected throughout a bathing season.

Table 15: Standards, quantification limit and test performed for the different measurements listed in the previous table

Analysis	Standard	Quantification limit	Test performed
E. Coli	NF EN ISO 9308-3 of March 1999	**Bathing water:** IQL: 15 NPP/100 mL SQL: 3.5 x 10^4 NPP/100 mL **Surface water:** IQL: 38 NPP/100 mL SQL :3.2 x 10^6 NPP/100 mL	Research and enumeration of Escherichia coli and coliform bacteria in surface and wastewater (miniaturized method (MPN) by inoculation in liquid medium)
Enterococci	NF EN ISO 7899-1 of March 1999	**Bathing water:** IQL: 15 NPP/100 mL SQL: 3.5 x 10^4 NPP/100 mL **Surface water:** IQL: 38 NPP/100 mL SQL: 3.2 x 10^6 NPP/100 mL	Research and enumeration of intestinal enterococci in surface and wastewater (miniaturized method (MPN) by seeding in liquid medium)
Turbidity	NF EN ISO 7027-1 of August 2016	0,5 FNU	Turbidity determination
Suspended matters (MES)	NF EN 872 of June 2005	2 mg/L	
BOD_5	NF EN 1899-1 NF EN 1899-2	0,5 mg O_2/L	Determination of the biochemical oxygen demand after n days - Part 1 & 2
COD	NF T 90-101 of February 2001	30 mg O_2/L	Determination of the chemical oxygen demand
DOC	NF EN 1484 of July 1997	0,3 mg C/L	Determination of dissolved organic carbon
NH_4	NF EN ISO 11732 of August 2005	0,01 mg/L NH4	Determination of ammoniacal nitrogen by flow analysis (CFA and FIA) and spectrometric detection
NO_2	NF EN ISO 13395 of October 1996	0,01 mg NO_2/L	Determination by ion chromatography
NO_3	NF EN ISO 13395 of October 1996	0,5 mg NO_3/L	Determination by ion chromatography
PO_4	NF EN ISO 15681-2 of June 2005	0,02 mg PO_4/L	Spectrometric determination using ammonium molybdate

2.1.3. Troubleshooting with on-line sensors and auto-samplers

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The auto samplers were not very reliable and required weekly maintenance to ensure a proper operation. Out of 214-programmed samples, 208 were actually collected.

In addition, the turbidity sensors in the Seine River and in the Marne River required regular maintenance. The turbidity and conductivity probes in the Seine River experienced data losses and were replaced twice. The turbidity probe installed in the Marne River failed due to a handling error. On the contrary, the turbidity probe in the Seine River did not experience loss of data.

In conclusion, the measurement campaign carried out on these four sites was successful, despite some challenges were experienced. The lack of reliability of the automatic samplers (ISCO autosamplers) required constant monitoring by the technicians. For example, it was observed that sometimes the automatic samplers were not triggered, even though a signal was acquired by the instrument. Some other times the suction tip of the samplers was blocked. In addition, in a further circumstance, an electrical short circuit during a rainfall event hampered the accomplishment of the measurements.

At the beginning of the 2021 campaign, a turbidity sensor was connected to the ALERT System V2, taking advantage of its new capability to log external sensors. The turbidity was chosen, since this parameter could be used to detect a rain event. It was decided to log the sensor at five minutes intervals, with the data accessible in real time through Fluidion data management interface.

However, approximately 2 weeks after the beginning of the campaign, the sensor broke down and had to be removed. It was sent back to the manufacturer for repair, which could not be accomplished in time for the campaign.

No auto-samplers were used during the 2021 measurement campaign. Instead, a technician from the laboratories of SIAAP performed spot sampling every Tuesday morning, at the same place where the ALERT system was installed. The water sample was collected with a bucket at the same location the ALERT system was installed and then was split between the physico-chemical and bacterial analyses.

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2.1.4. Installation, operation and maintenance of ALERT V1 in Paris

At each selected site described previously, ALERT instruments were installed.

Fluidion has developed two models of the ALERT technology: the ALERT system, which allows in situ and on-line measurements of the bacteriological quality of water, and the ALERT lab, which is a portable device that allows off-line measurements of bacteria in situ on samples taken manually (Figure 16 and Figure 17). In the latter system, the samples are incubated and monitored automatically, and the data are transmitted wirelessly.

In this experimental campaign, both ALERT Lab and ALERT System were used. ALERT System was used during the monitoring campaigns in the Marne and Seine rivers, whereas the ALERT Lab was used for all stormwater data analysis, and for analyzing the samples collected by drone. The objective of the experimental campaigns was to validate ALERT measurements by comparing them to measurements performed in the laboratory. However, the ultimate goal of this project is to use ALERT System for the realization of the EWS.

The biological analysis in the lab were conducted following the MPN Microplate ISO 9308-3 technic which uses only 18 mL of sample that is diluted twice. Ultimately, only 2 mL of diluted sample is used for the analysis. As opposed to the Fluidion process that uses 25 mL of sample. The comparison analysis was then performed by applying the ISO 17994:2014 and the EPA Site-Specific Alternative Recreational water protocols.

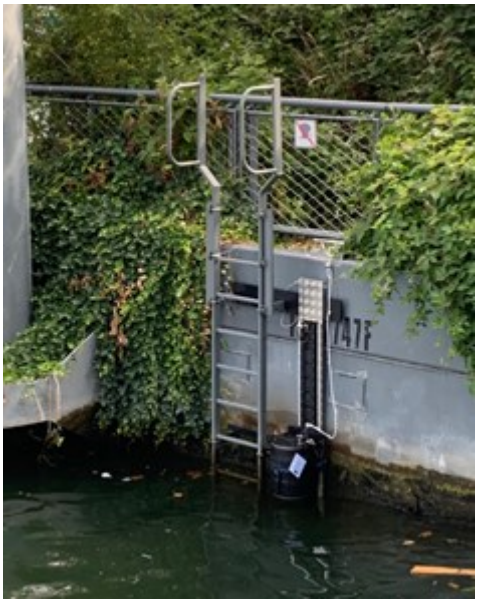

Figure 16: ALERT System V1 installation for long term monitoring in Seine River during DWC campaign

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Figure 17: Sampling materials of ALERT

Drone sampling campaigns

An experimental campaign to study the spatial variability of water quality was conducted using a drone developed by Fluidion in both the Seine River and the Marne River. This is a radio-controlled boat that allows sampling of water at specific location identified by GPS. The boat has 12 bottles and sampling is performed by placing a 1L bottle under vacuum. The total duration of the sampling was about 30 - 45 minutes (Figure 18).

Figure 18: Fluidion DRONE usage for sample collection for performing spatial variability analysis in Marne river

At the end of the sampling campaign, collected samples were split in two aliquots. One aliquot was immediately used and analyzed by Fluidion's ALERT Lab, while the other one was brought to the laboratory for bacteriology and physic-chemical analyses.

During the first campaign in the Marne River, the route had an upstream direction for samples 1 to 6 and a downstream direction for samples 7 to 12 (Figure 19 - bottom left). During the collection of samples 7 – 12, the sampling route was zigzagged to avoid collecting the same water multiple times (Figure 19– bottom right).

During the sampling campaign on the Seine River, the use of the drone was subjected to authorization from HAROPA, which imposed the end of the experimental activities before 9:00 a.m. in order to avoid interferences with the navigation of ships. In this case, samples were collected both close to and off-shores the riverbank (Figure 20).

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The data obtained from both variability studies are available in the Annex A.

Figure 19: Fluidion DRONE recorded GPS trace and sampling locations in Marne river

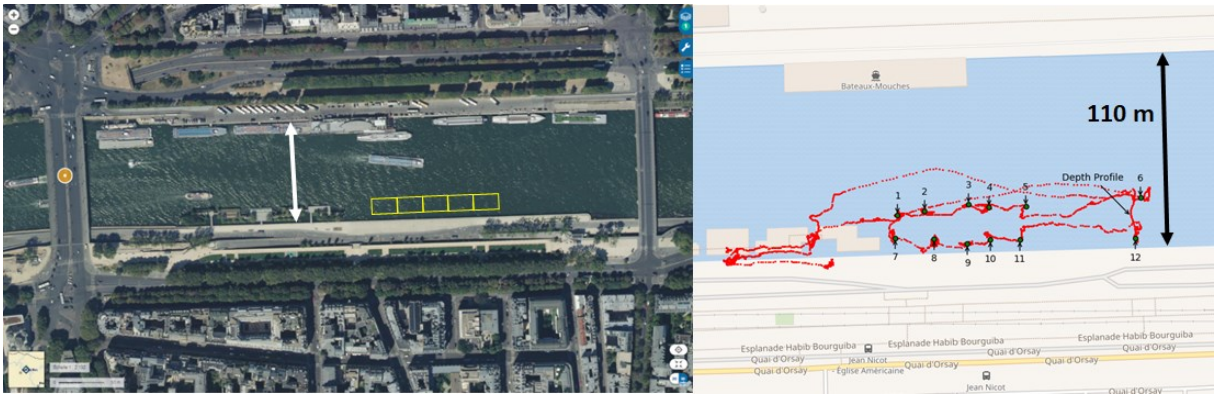

Figure 20: Fluidion DRONE recorded GPS trace and sampling locations in the Seine River

2.1.5. Troubleshooting with ALERT V1

Setting up and operating the ALERT System was simple and reliable. No serious operational problems were encountered during in-situ measurements. Indeed, out of the 166 determinations performed, only four values were missing. Fluidion personnel performed regular maintenance procedure on ALERT System before every new sampling campaign. The maintenance operations took around 30 minutes. It consisted of removing the used vials and filling the sampling tubes and check valves with a disinfectant solution. The disinfectant solution acted for 15 minutes, and then all tubes and check valves were rinsed with de-ionized water.

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Thus, the new vials with reagent were added to the system, and the battery was replaced with a previously recharged one. These regular maintenance operations were the same for all the three case studies (i.e., Paris, Berlin, Milan).

In conclusion, the experimental campaign carried out with the ALERT lab systems was successful, confirming that ALERT lab is a reliable and easy to use tool for bacteriological analysis.

However, a technician is still needed to collect the samples. It would be interesting to modify this element so that all steps could be done automatically (sampling and measurement) without any intervention.

2.1.6. Installation, operation and maintenance of ALERT V2 in Paris

As previously explained, the conditions of choice of the measurement site included an easy and secure access. It was important for the ALERT System V2 to be installed at a place where it could not be moved or detached. Thankfully, the installation site could only be accessed by a locked gate.

Once the site was selected (Figure 21), the specific place in the water where the ALERT System V2 would be installed needed to be decided. The ALERT system V2 was fixed on a rail that was attached to a small ladder, as seen on the picture below. The rail had to be partially submerged, and then the ALERT V2 was fixed on the rail. Since the water level could change slightly during a measurement campaign, this process of installation allowed vertical movement of the ALERT V2, according to the water level. This ensured that it was always submerged at the right depth for sampling.

Figure 21: Alert V2 installation site

Like the ALERT V1, the ALERT V2 has the ability to perform seven measurements into seven individual cartridges. The measurements can be initiated at any time of the day and night via a secure cloud interface.

The ALERT V2 interface (Figure 22) provided two options:

- A button “Take a sample” that started an immediate measurement by clicking on it.
- A button called “Schedule” that allowed programming a measurement at any time of the day and night.

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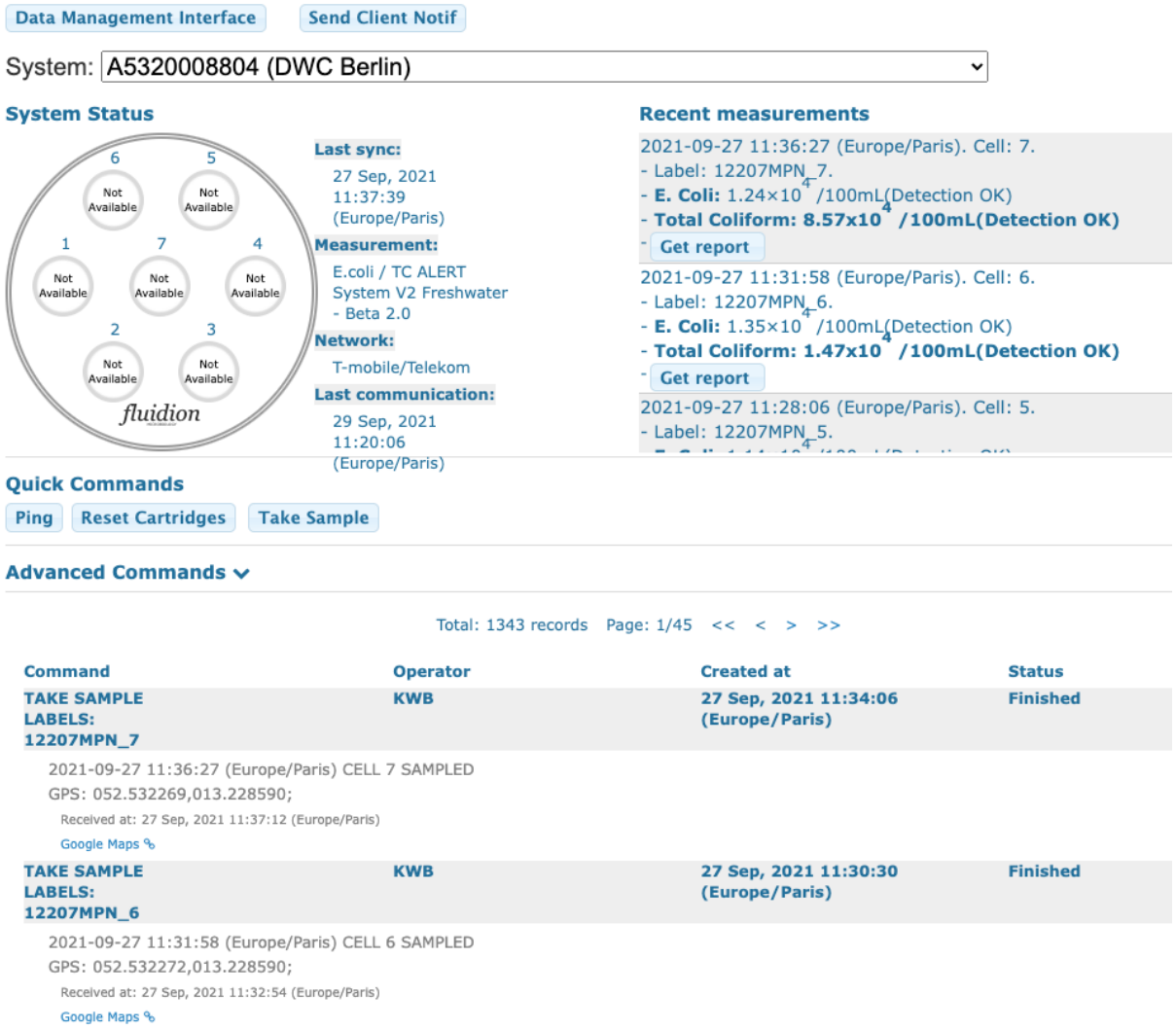

Figure 22: Alert V2 interface

The first option was usually used to sample at the same time as the technician of SIAAP on Tuesday, so that the results could be compared. The second option was very useful for the rest of the dry weather samples and, of course, the wet weather. Indeed, it happened often that the rain event that needed to be sampled would occur during the night. A sampling could thus be scheduled at the date and hour required.

The results, graphs and report could then be accessed via a different option on the same secure cloud platform, as seen in Figure 23.

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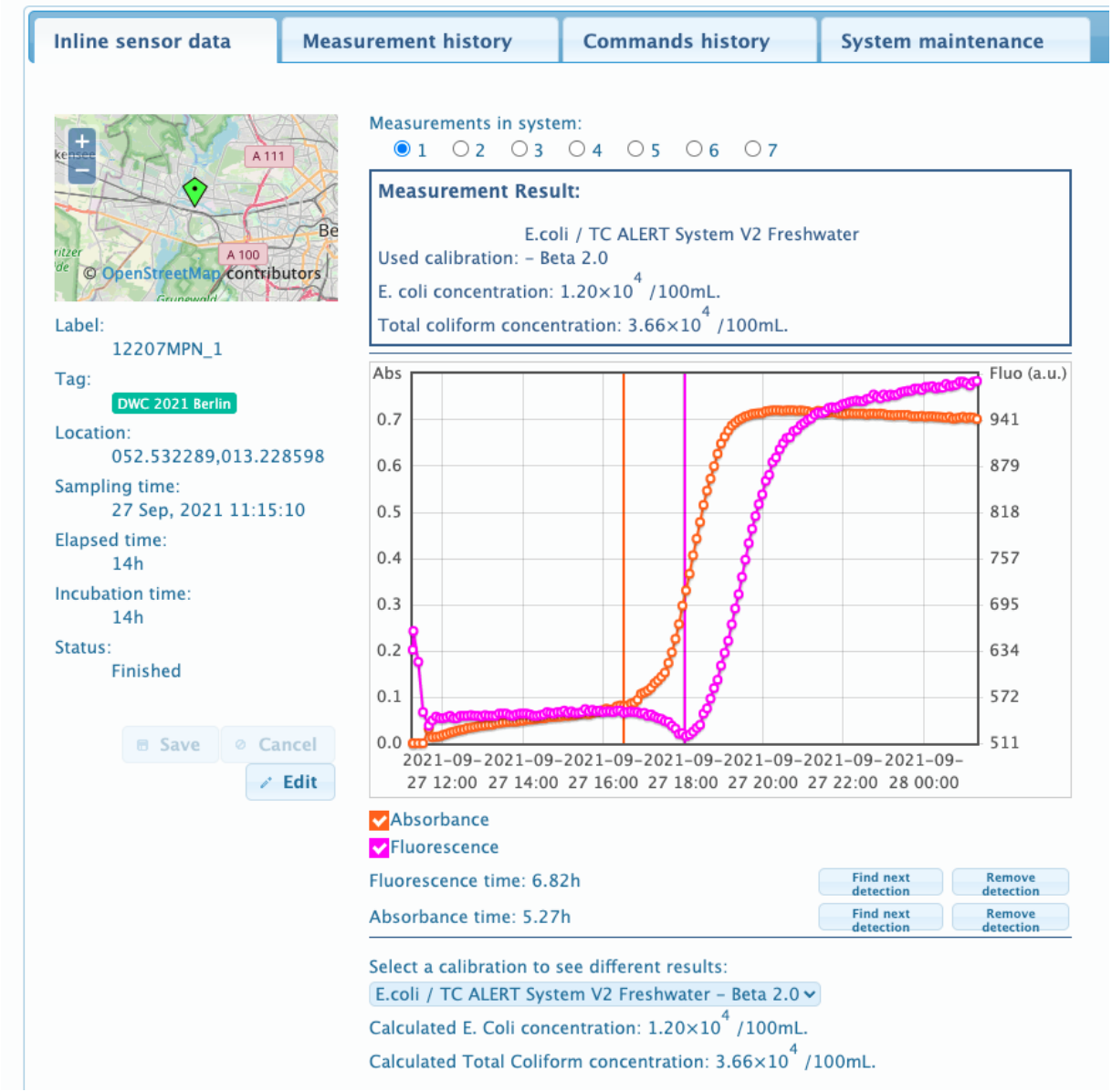

Figure 23: Results platform

It took generally between 6 and 11 hours for a sample to be processed, for the concentration ranges observed in the campaign. After the use of all the 7 samples, a technician from Fluidion went on the site to perform a rapid maintenance procedure, consisting of changing the battery and the seven cartridges.

The maintenance of the ALERT system V2 took approximately 5 minutes. First, the lid needed to be opened to change the battery. This was done by simply unplugging the old one and plugging in a freshly charged one. A small LED lighted up to indicate when the system was connected to the cell network and was able to transmit data and receive commands. Then, the ALERT V2 needed to be turned upside-down (or placed on its side) to have access to the cartridges and remove them. Afterwards, the new clean cartridges could be loaded into the ALERT system V2, that was again ready to be used.

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Considering the random nature of a rain event, it was tricky to plan the maintenance accordingly. However, through good collaboration with Fluidion, every maintenance was planned during the week and in suitable time periods.

The enhancement of the ALERT system from the V1 to the V2 is undeniable. Technicians performed a maintenance on both systems next to each other, to compare them and evaluate the upgrade. First, in the matter of time, it took almost 45 minutes to do the maintenance on the ALERT V1, versus the 5 minutes that required to prepare the ALERT System V2.

Once opened, the ALERT V1 contained a small sampling tube connected to every sampling bottle on one end, and to the system on the other end, which means that there were 7 tubes that needed cleaning and disinfection. Once the tubes were removed from the bottles, a syringe filled with diluted bleach needed to be used to send disinfectant through the tubes. After the bleach, deionized water needed to be flushed in order to rinse the tube and, finally, it was used a syringe filled with air to dry it.

There were check valves filters used in the ALERT system V1, at the end of every sampling tube that was connected to the system. Each one of these check valves needed to be cleaned with the same routine: diluted bleach, water, and air.

For the ALERT V1, the sampling bottles were not disposable, which meant that every time the seven bottles were used, they had to be emptied, disinfected, and dried before being used again.

This kind of maintenance was long and difficult to realize, even more by a person alone and in field conditions.

The maintenance of the ALERT system V2 avoided most of these steps. First, there were no tubes, the sample arrived directly into the cartridges in which there already were filters and check valves. The first step that it took to perform the maintenance of the ALERT System V2 was to remove the cartridges that were filled with the previously analyzed samples. Considering that for the new version the cartridges are disposable, it was only needed to replace the old ones with new ones. The old ones were disposed according to specific regulations for biological wastes.

In conclusion, the improvement of the ALERT system in terms of maintenance was indisputable. Due to the convenience of this new process, one person can carry out the maintenance easily, directly in the field, in a short amount of time (under 5 minutes), without requiring complex specific training. In addition to that, the fact that there are no tubes, valves, and bottles to clean eliminates the possibility of cross-contamination or disinfectant residual being present and distorting the results.

2.1.7. Troubleshooting with ALERT V2

Ultimately, during the two months of use of the ALERT System V2, there were not difficulties or serious issues. The staff was able to launch every sampling event and retrieve all the measurement results.

It happened only twice during the measurement campaign, that the system did not respond, and a sampling could not be initiated immediately. This issue was due to poor networking, since the connection with the servers was temporarily compromised. However, the problem was solved very quickly and did not happen again.

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2.2. Demo-case in Berlin: Canal water study

The ALERT-system was installed for two consecutive years (2019, 2020) at the location “Spree-Canal”, which is a side canal of the river Spree. The location is located within the boundary of Berlin combined sewer system and is periodically impacted by discharges from combined sewer overflows (CSOs) (Figure 24 and Figure 25). At the Spree-Canal the project FLUSSBAD aims at re-establishing and open water swimming location. An open question at this location is the management of CSOs.

In addition, compared lab microbiological measures were also performed in 2020-2021 on the treated wastewater discharged from one of the WWTP discharging in the Spree Canal. Additional to the ALERT System, the ALERT Lab was used in 2020 to complement the in-situ measurements of the ALERT System with additional analyses.

Figure 24: Installation point Spree-Canal

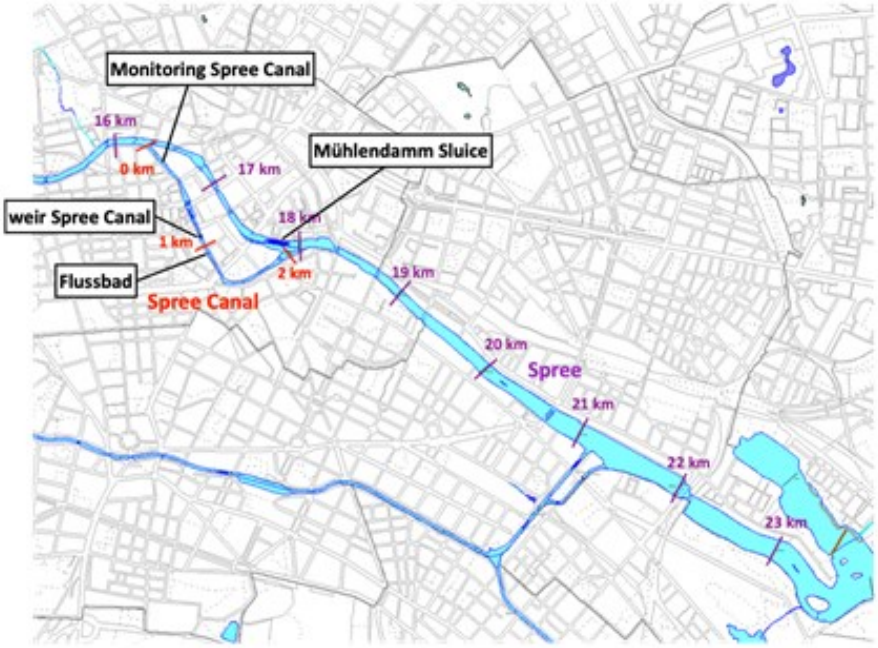

Figure 25: Location of the monitoring site at Spree Canal with river kilometer marks for Spree Canal and Spree River (Geoportal Berlin, 2020)

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2.2.1. Installation, operation and maintenance of ALERT V1 in Berlin

In Berlin, the monitoring campaigns in 2019 and 2020 differed regarding their level of detail – the ALERT System was in both cases installed in the Spree canal at the same location.

In 2019, side-by-side measurements between the ALERT System and the accredited laboratory of the Berlin Water Utilities (BWB) were conducted. The laboratory analyzed the samples for *E.coli* according to DIN EN ISO 9308-3:1999-07. The signal of sample taking for the ALERT System was given by SMS or internet protocol through GSM/GPRS (Angelescu and Hausot, 2019). The parallel grab samples were taken within one minute, when the SMS signal was given to the ALERT system. Laboratory samples were taken manually, in sterile PE bottles.

The sampling period was from August 8th, 2019 to September 29th 2019. During this period, 68 paired data points were collected at the location Spree-Canal. Samples were collected between 10 and 12 a.m.. For transport, lab samples were cooled in cooling boxes. Laboratory samples were analyzed at the same day the sample was taken. During the sampling period, unfortunately no CSO was observed in Berlin. Therefore, the concentration range, which could be sampled during this campaign, was comparatively small as it only included dry weather samples.

In 2020, side-by-side sampling in surface waters started at June 17th and ended at September 9th. In comparison to 2019, the level of detail increased as both the ALERT System as well as the ALERT Lab were used to conduct investigations. As in 2019, two samples were taken each morning (weekdays) with the ALERT System (Annex A). The time difference between both samples was 10 min or less. For each sample side-by-side samples were taken manually. Two aliquots of each manual grab sample were used for duplicate measurements on-site with the ALERT Lab. Two further aliquots of each manual grab sample were filled in sterile bottles (in total 4 bottles) for laboratory duplicate analysis according to ISO 9308-3. Eventually, a last aliquot was filled into another sterile bottle for later analysis with the ALERT Lab. This sample was analyzed at 3:30 p.m.. This time was chosen because the laboratory starts incubation between 1 and 5 p.m..

Between taking the sample and its analysis with the ALERT Lab, the sample was transported in a cooling box to KWB and stored in a refrigerator. Thereby, this sample was in at least two ways different from the ALERT lab sample analyzed directly on-site.

- First, during the time between the two analyzes potential degradation may lead to lower concentrations in the afternoon sample.
- Second, the afternoon sample was considerably colder than the sample, which was analyzed directly on-site, even though it was taken out of the refrigerator about 15 min before its analysis. Thereby, the lag phase of the microbial growth might me prolonged leading to longer time span necessary for producing of a fluorescence signal, which in turn also would lead to lower measurements with the ALERT Lab. To discriminate the degradation and temperature effects, an additional experiment would be necessary. The sampling protocol is illustrated in Figure 26.

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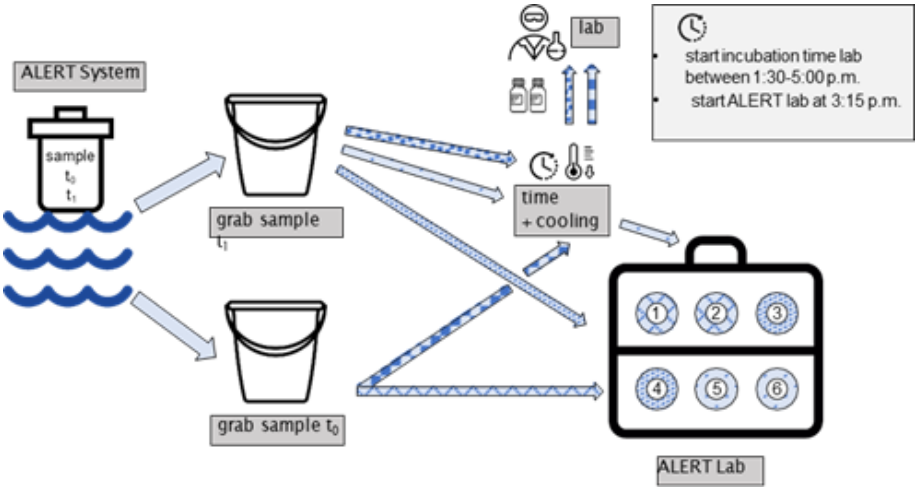

Figure 26: Overview of sampling protocol 2020

The maintenance of the V1 included a systematic cleaning and disinfection of all components and took about 1 hour. This required disinfecting all sampling vials, adapters, tubing and check valves with a bleach solution, followed by thorough rinsing with deionized water to prevent residues of bleach in the system that could affect the analysis. Eventually, the components had to be air-dried before they could be used again for analysis. Once the vials were cleaned and dried, they could be manually refilled with 1 mL of reagent, connected to a sampling and vacuum tube and placed in an incubation cell in the system.

Repeatability study 2020

In 2020, a repeatability study was conducted with both the ALERT System and the ALERT Lab in order to complement the side-by-side comparison conducted in surface waters and add repeated measurements at concentrations levels that could not be obtained in-situ due to the dry weather conditions. The objective of the repeatability study was to quantify the bias and the precision of the ALERT System and ALERT Lab through repeated measurements at different concentration levels under controlled conditions, against the laboratory reference method. For the study, artificial samples with concentrations targeting the range from 50 to 10000 MPN/100mL were created from filtered river water and secondary effluent from the Ruhleben WWTP. To generate a water matrix similar to the river but that can be subjected targeted spiking, 50 L of river water were filtered over 0.45 µm in order to remove all E.coli bacteria, whether dispersed or particle-bound.

A daily manual grab sample of the secondary effluent of the Ruheben WWTP was collected and used for spiking the filtered river water matrix. Sample preparation and spiking were performed in a container directly on-site within the WWTP. All preparation equipment was disinfected with ethanol (>70%) the day before sample preparation and was clean and dry. The sampling equipment is shown in Figure 27.

The secondary effluent was filtered over 5 µm in order to remove particle-bound bacteria. After filtration of the secondary effluent, 6.5 L of spiked samples were prepared each day. The filtered surface water was first poured in a 20 L canister, and then spiked with secondary effluent according to the dilution series in Table 16. The 20 L canister was flushed with river filtrate before preparing the actual sample.

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The target log-concentration followed an equidistant distribution. However, as the concentration of the secondary effluent was not known a-priori and varied between days, the actual concentrations differed from the target concentrations, which can be considered a rough estimate. Dilutions were prepared with increasing concentrations and labeled 1.1, 2.1 … to 7. On day 8 and 9, the dilutions 1.2 and 2.2 were also prepared. Dilution 1.1 was repeated (as 1.2) since most samples in 1.1 were below the limit of quantification of both the laboratory and of the ALERT instruments. Dilution 2.1 was repeated (as 2.2), because in the first run the data from the ALERT System were lost due to communication issues (for dilution 2.2 only the ALERT System was used because of limited surface water filtrate).

By mixing 6.5 L in a 20 L canister enough spare volume was guaranteed to allow for turbulent mixing. For mixing, the 20 L canister was moved manually from top to bottom and from left to right to create turbulences and “roll-over” movements. After that, the procedure was repeated with the canister being tilted over by 90 degrees and the canister being pushed and pulled horizontally.

After this first homogenization, laboratory samples were prepared. On the first two days of the study, 150 mL were filled directly from the 20 L canister into sterile PE bottles provided by the laboratories. From day 3 to day 9 the volume was first poured into a 500 mL beaker, which eased the process of subsequently filling the PE bottles. Before using the beaker, it was flushed with sample. In total 24 samples were prepared, 12 for each laboratory.

After sample preparation, the laboratory samples were placed in coolers. A second team collected the samples and transported them to two independent, accredited labs located in Berlin and Potsdam. The labs received 12 separate bottles and were not informed about the fact that the bottles would contain aliquots of the same sample.

After preparation of the laboratory samples, the maintenance, i.e. the systematic cleaning and disinfection of the ALERT System took place following the instructions provided by FLUIDION. During this time, the 20 L canister was put into a refrigerator. The maintenance took place after preparing the laboratory samples so that the time between ALERT analysis and laboratory analysis would be as small as possible.

After maintenance of the ALERT System, the 20 L canister was homogenized (shaking) once more for preparing the samples for the ALERT Lab and the ALERT System. For doing so, sample volume from the 20 L canister was filled into a 500 mL beaker. From the 500 mL beaker samples for the ALERT Lab were collected using a sterile syringe and placed in the corresponding measurement vial. Before taking the sample with the syringe the sample was stirred slightly.

For the ALERT System, volume from the 500 mL beaker was filled into a smaller beaker of 100 mL. For sampling, the sampling tubes of the ALERT System were put into the 100 mL beaker and the sampling was started using the SMS protocol.

From the 100 mL, the ALERT System draw 25 mL sample. The smaller beaker was taken so that the sampling tube stayed below the water surface for the whole sampling time even after 25 mL were extracted, so it would not draw any air. After each sample, the 100mL beaker was slew and 25 mL were refilled from the 500 mL beaker. This procedure was repeated 7 times for the 7 samples of the ALERT System.

ALERT data acquired in Berlin are reported in Table A3 and Table A4 (Annex A).

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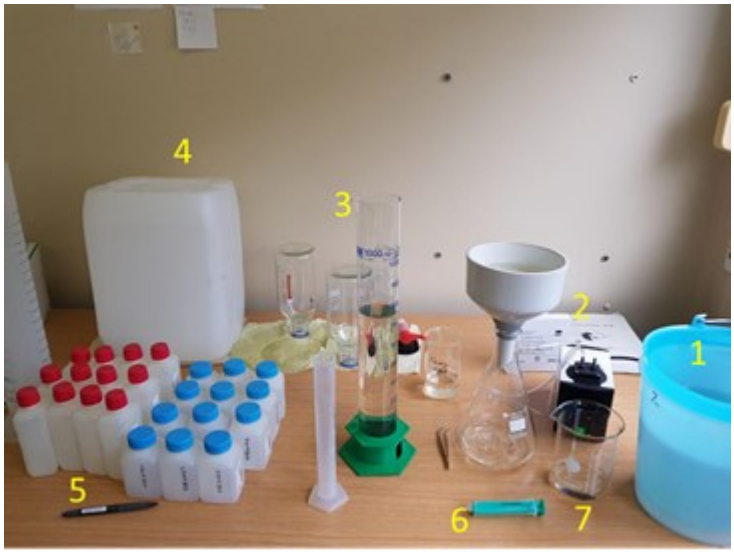

Figure 27: Material used for conducting the replication. 1: Sample of secondary effluent, 2: filtering equipment, 3: measuring cylinders, 4: 20 L canister, 5: PE bottles for the two laboratories, 6: Syringe, 7: beaker

Table 16: Overview of applied dilution series for the repeatability study

step	dilution	c_{target}(MPN/100mL)	Log(ctarget)
1.1	1/600	50	1.70
1.2	1/600	50	1.70
2.1	1/240	125	2.10
2.2	1/240	125	2.10
3	1/100	313	2.49
4	3/100	781	2.89
5	7/100	1953	3.29
6	1/6	4883	3.69
7	2/5	12207	4.09

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Figure 28: Fluidion ALERT System V1 installed in Spree-Canal for DWC campaign in 2019

2.2.2. Troubleshooting with ALERT V1

In terms of troubleshooting, some communication issues were observed in Berlin in 2020 at the beginning of the sampling campaign, that were due to the implementation of a new communication protocol using global SIM cards. Previously (2018, 2019) no communication issued had been observed. Since the communication issues could not be immediately resolved, the protocol was reverted to the previous version and the study continued without problems.

2.2.3. Installation, operation and maintenance of ALERT V2 in Berlin

The maintenance of the ALERT System V2, which needs to be carried out every seven measurements, differed significantly from the maintenance of the ALERT System V1.

The maintenance of the V1 included many procedures for cleaning and disinfection of all components, as well as reagent refilling. As shown in the results part, it seemed that this complex maintenance procedure had the potential to introduce errors from presence of even minute amounts of disinfectant residual, which reduced the precision of the ALERT System V1 compared to the ALERT System V2.

In contrast, the maintenance of the ALERT System V2 was much simpler and took only a few minutes, as it only required the replacement of sample cartridges that were already filled with reagent (provided by Fluidion). The maintenance was done at the beginning of each day before the analyses. First the used sample cartridges (Figure 30) were removed with the cartridge installation tool. These cartridges were not reused but discarded in the biohazardous waste. The new cartridges were then inserted first into the cartridge installation adapter and then into the incubator port (see Figure 29). Using the cartridge installation tool, the sample cartridges were fixed in the port by turning the cartridge installation adapter clockwise. As this procedure is very simple, no issues occurred during the repeatability study. Moreover, no disinfection steps or additional materials were required other than the sample cartridges, as these are the only parts of the system that come into contact with the samples.

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For sampling from a beaker in the laboratory, an adapter with tubing was attached to the ends of the cartridges (this adapter is not required when deployed in the field). The tube was held in a beaker with the sample for the measurement (Figure 30). These adapters with tubing were replaced with new ones every day and after every dilution. Additionally, a beaker with deionized water was placed under the external temperature sensor, which was tempered in the same way as the autoclaved river water to provide the system with the correct temperature of the samples.

This simplified maintenance procedure combined with the use of disposable cartridges on the ALERT System V2 resulted not only in much faster maintenance, eliminating potential for human error, but also in major improvements in instrument precision, as visible in the results section.

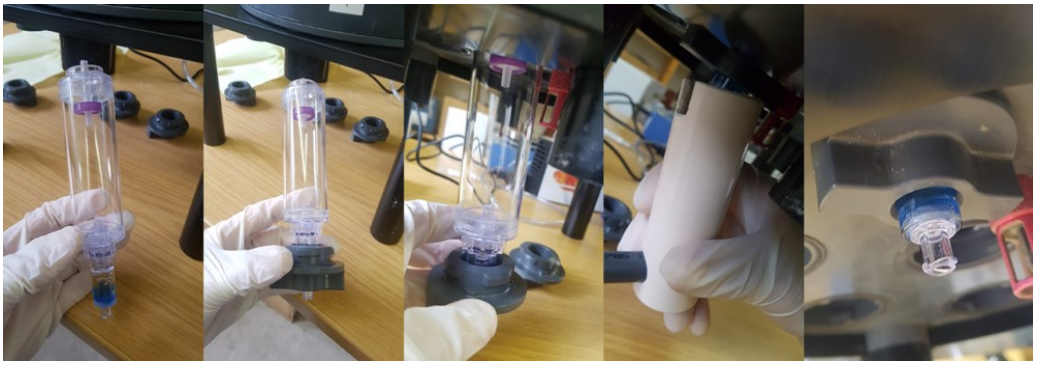

Figure 29: Maintenance of the ALERT System V2; Replacement of the sample cartridges.

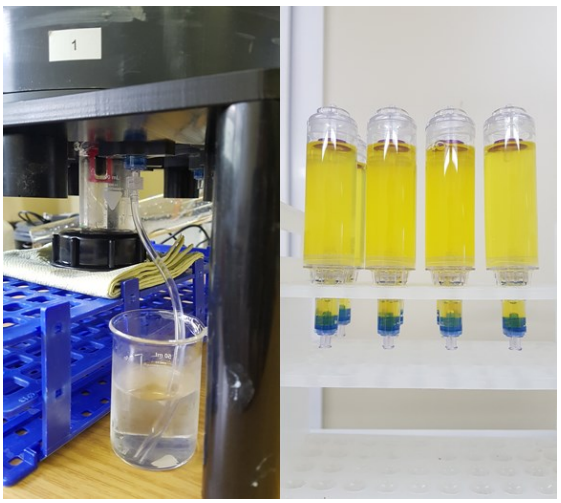

Figure 30: Left side: Sampling with cartridge 1 using a barb adapter with a tube. In the background: external temperature sensor. Right side: Filled sample cartridges after analysis.

2.2.4. Troubleshooting with ALERT V2

The ALERT V2 operated correctly, and no major issues were observed during the repeatability study.

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2.3. Demo-case in Milan: Reuse water study

This section reports experimental tests accomplished with ALERT Lab and ALERT System of Fluidion, and with sensors for conventional water quality parameters (TSS, NH_4, PO_4 and NO_3) installed at Peschiera Borromeo WWTP to monitor wastewater quality of the final effluent.

Experienced operational issues are described, and recommendations are reported for the installation of the on-line device for bacteriological analysis ALERT System. Further sensors were installed at the influent (pH, ORP, conductivity, TSS, NH_4, PO_4) and at the effluent (pH, conductivity, ORP, UV transmission and TOC) of the WWTP. In addition, in the Annex B are reported additional data related to experimental campaigns that used alternative sensors for E. coli determination in situ (i.e., devices that are commercial competitor of Fluidion systems), and laboratory analyses of other toxic compounds that were carried out at Peschiera Borromeo WWTP.

2.3.1. Measurement site: Peschiera Borromeo Wastewater Treatment Plant

Among the WWTPs managed by CAP, Peschiera Borromeo WWTP is located in the peri-urban area of Milan, in Via Roma - Cascina Brusada. It has a treatment capacity of about 566000 PE, and treats daily an average flow rate of 216000 m^3/d. As previously described, the plant has two separated treatments trains (i.e., Line 1 and Line 2), which treat the wastewater coming from the two sewer network sectors of the peri-urban region of Milan. Sewages coming from the area managed by Metropolitana Milanese are treated in Line 1, whereas the wastewater coming from the sewer sector controlled by CAP is treated in Line 2. Line 1 includes coarse screening, pumping station, fine screening, grit and oil removal, primary sedimentation, biological treatment for organic carbon removal, tertiary filtration combined with nutrient removal in BIOFOR reactor and chemical disinfection with peracetic acid. Line 2 includes coarse screening, pumping station, fine screening, a compact SEDIPAC unit for grit and oil removal coupled with primary sedimentation, a BIOFOR unit for organic and nutrient loads removal combined with tertiary filtration and a final disinfection treatment with UV.

2.3.2. Installation, operation and maintenance of on-line water quality sensors at Peschiera Borromeo WWTP

The reliability of early warning systems relies upon the accuracy and precision of online monitoring tools for physical, chemical, and microbiological measurements. Therefore, it is crucial to establish whether sensors and analyzers can guarantee collection of trustable data. Moreover, the system should be also able to discriminate between anomalous contamination events and errors of the measurement.

In the past years, Gruppo CAP has acquired significant practical experience in dealing with the operation of several sensors designed to measure conventional wastewater quality indicators such as nitrate, phosphate, COD, total suspended solids, and ammonia.

Precision and accuracy of the instrument as well as the chemical-physical principle used by the device are relevant factors to evaluate the overall performance of the measurements. However, several issues, not directly connected with the technology of the sensors, can be faced during on-line measurements. These issues include fouling of optical sensors, pipeline clogging, algae formation, and communication disconnection. Some of those issues might be avoided by accomplishing periodic maintenance. However, it implies the presence of qualified personnel at the WWTP. On the other hand, some other issues depend on external factors, such as the occurrence of severe meteorological events.

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The Peschiera-Borromeo WWTP, which has a complex treatment train, was upgraded recently to comply with national standard limits. In addition, Gruppo CAP has a significant experience in the management of online monitoring systems in several wastewater treatment plants. For example, Figure 26 (provided by Gruppo CAP) shows the correlation observed between lab and sensors data for nitrate measured at PERO WWTP, which is located in the northwest part of the peri-urban area of Milano.

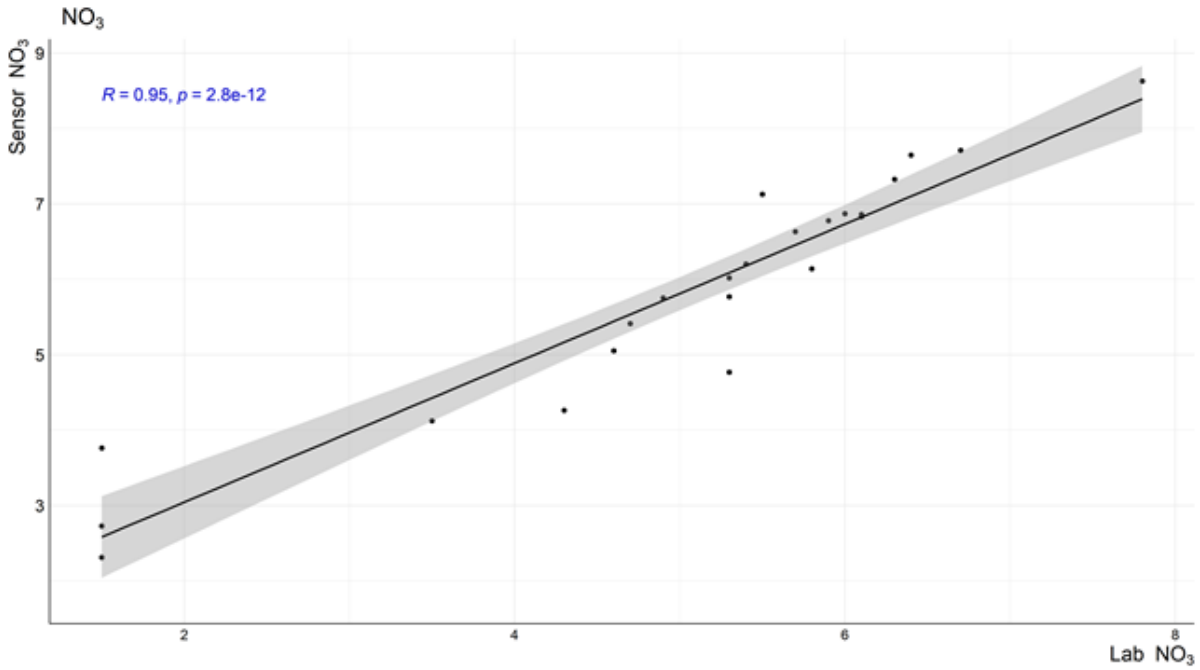

Figure 31: Correlation between nitrate measurements obtained by sensor and laboratory analyses in Pero WWTP

Summarizing, Peschiera Borromeo WWTP, which treats wastewater in one of the largest metropolitan areas in Europe, is a highly challenging scenario for the application of early warning systems based on the on-line monitoring of wastewater quality, and this plant can be considered representative for the application of similar systems in other WWTPs.

Chapter 3 presents and describes the main features of sensors already installed at Peschiera-Borromeo WWTP. Those sensors enable the on-line monitoring of NH_4, PO_4, NO_3, and TSS, which are parameters currently regulated worldwide for wastewater treatment. Furthermore, in Chapter 3, are also described the technical characteristics of the new sensors that have been recently installed at Peschiera-Borromeo WWTP. These latter sensors will enhance the monitoring of wastewater quality of the final effluent allowing the measurement of pH, Conductivity, Oxygen Reduction Potential (ORP), UV transmittance at 254 nm, and Total Organic Carbon (TOC). The new sensors also allow the real-time measurements of pH, conductivity, ORP, conductivity, NH_4, PO_4 and TSS at the inlet.

In particular, the use of TOC sensor could represent a rapid and precise instrument to control the quality of wastewater in real time, and particularly the organic content of the treated wastewater. In fact, differently than BOD_5 and COD, TOC measurement is fast (around 7 minutes are needed for its determination) and precise, and it can be accomplished by on-line devices. On the contrary, determination of BOD and COD need to be performed in the laboratory and require long time for analysis.

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Regulatory measures for water reuse in Europe have fixed standard limits for COD and BOD in the final effluents. However, due to the abovementioned issues, BOD and COD cannot be monitored in real-time. TOC determination can overcome these problems, by an alternative approach that provides for a transition from TOC to COD values, and from these to BOD_5, to derive correlation factors with good reliability. It is not always easy, but it is possible on the basis of the characteristics of the various plants and the "historical" data.

The installation of the sensor for the measurement of TOC was particularly challenging and time spending, due to the particular nature of the device. Indeed, BioTector B3500e is a laboratory appliance, designed to operate indoor, that has been adapted for field operations. Therefore, further equipment was required for its full operation, such as an air conditioner, to ensure proper outdoor operation, despite temperature changes. The need for these appliances has caused delay in the installation.

Further delay has been caused by the choice to build a custom cabinet, to ensure reliability of the device, instead of the standard product provided by the supplier. Despite the delay, this might result in better accuracy and reliability of measurement. The cabinet has been specifically designed for the BIOTector B3500e and built by CAP.

However, the connection for the acquisition of the sample in series with the other analyzers is completed and the BioTector B3500e is now functioning.

By combining the practical experience gained operating the sensors and the assessment of the quality of data collected during the monitoring campaign, important conclusions can be drawn regarding the implementation of a novel and reliable monitoring system. Information such as the most suitable location for the installation of sensors at the WWTP, maintenance frequency to avoid clogging issues, and other useful information can be obtained by this investigation for a proper operation of a sensors network for wastewater quality monitoring.

2.3.3. Troubleshooting of on-line sensors for water quality monitoring

Data from online sensors and probes installed at Peschiera Borromeo WWTP were characterized by the presence of anomalous values, which should be considered as outliers, since they were not representative of the effective water quality. Outlier data were affected mainly by measuring/recording issues.

A defined plan of periodic interventions and maintenance is not established at Peschiera-Borromeo WWTP, since in most cases operators intervene only when malfunctioning or other issues are detected. Moreover, those interventions are not recorded, so it is not very feasible to correlate outliers with the occurrence of a specific event or malfunction in the plant. Hence, to solve those issues a maintenance plan will be drafted to improve the quality of the acquired signal from all the installed on-line sensors. Since sensors are sensible to fouling, it is recommended to increase the frequency of maintenance and cleaning procedures, in order to improve the quality of the signals. Moreover, it should be advisable to define routinely maintenance plans and to report exactly the reasons of the interventions and the actions applied. It is also recommended to keep recording anomalous events that might have affected sensors measurements, in order to be able to identify the sources of outliers and distinguish them depending on their causes.

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2.3.4. Operation and installation of ALERT LAB and ALERT V1 in Milan

For 2019 – 2020 sampling campaigns, Alert Lab was tested along the main WWTP treatment units, while for 2021 sampling campaigns, the Alert Systems V1 and V2 were installed before the UV disinfection unit.

From September 2019 to January 2020 the ALERT LAB was tested, and its outcomes were compared with laboratory determinations. Bacteriological analyses of wastewater samples were performed by the Fluidion ALERT Lab device and in the microbiological laboratory of the CAP Group. The monitoring campaign was implemented in Line 2 of the WWTP, where three different sampling points were selected:

- IN-BIO: Before biological treatment, performed with BIOFOR system;
- IN-UV: Before the UV disinfection treatment;
- OUT-UV: After the UV disinfection treatment (i.e., the final wastewater effluent).

Furthermore, a lower number of samples was analysed also from the Line 1 of the WWTP. Sampling points were:

- IN-OXI: Before biological oxidation;
- IN-PAA: Before the disinfection treatment with peracetic acid;
- OUT-PAA: After the disinfection treatment with peracetic acid, corresponding to WWTP effluent.

A schematic of Peschiera-Borromeo WWTP with indication of selected sampling points is shown in Figure 32.

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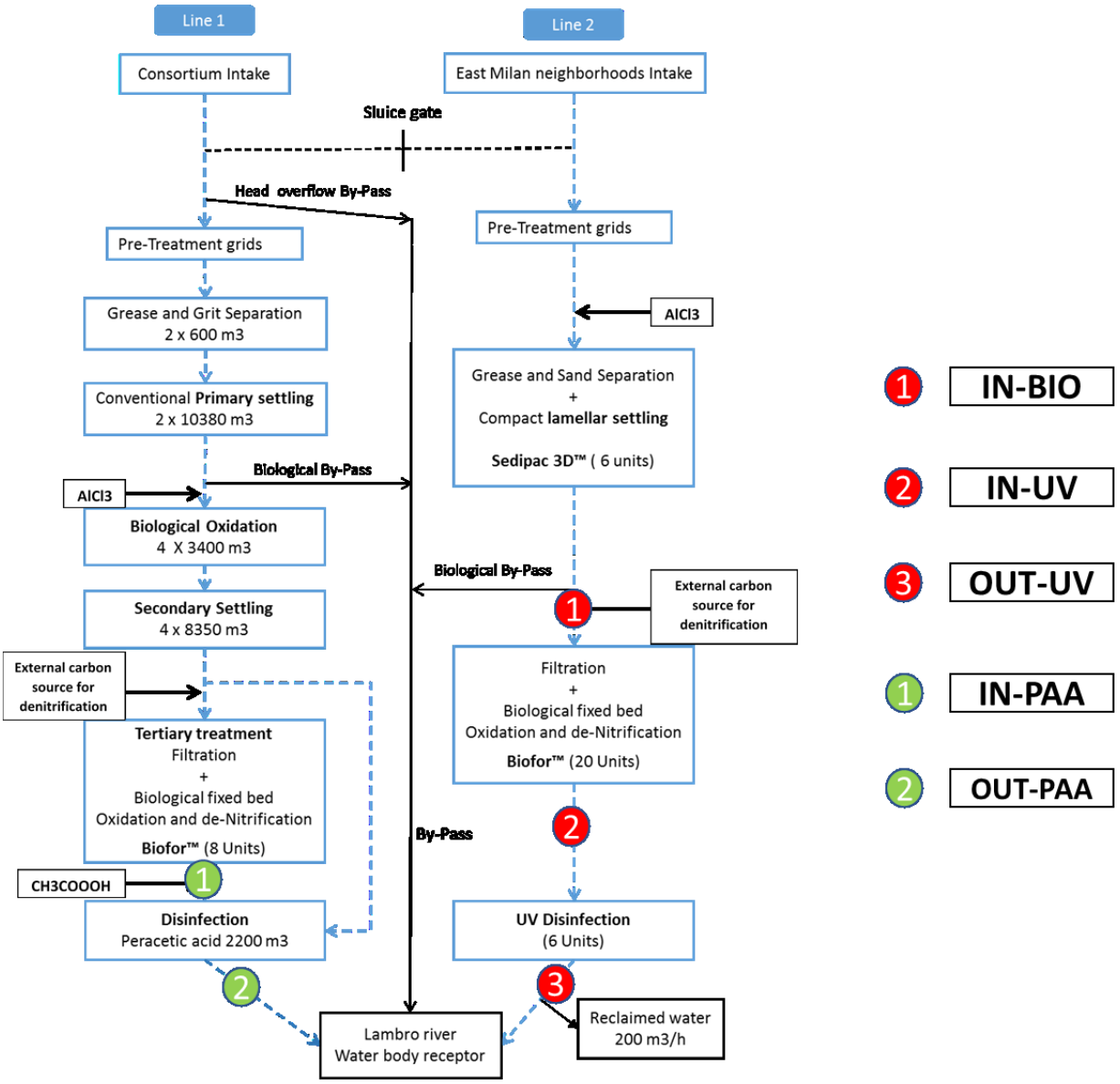

Figure 32: Peschiera Borromeo WWTP and sampling points for ALERT Lab testing

The monitoring campaign was performed by analysing 6 samples per day, two per each sampling point, which were withdrawn during the morning with 3-4 hours of interval. During the fourteen days of measurements, which were carried out between October and November 2019, several sampling points were assessed and compared with reference laboratory measurements in order to select the most suitable location (i.e., IN-BIO, IN-UV, OUT-UV, IN-PAA, and OUT-PAA). Collected data are shown in the Annex A (Table A2).

Alert System V1 was installed before the UV disinfection unit, as shown in Figure 33.

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Figure 33: installation of the ALERT System at Peschiera-Borromeo WWTP

2.3.5. Trouble shooting with ALERT LAB and ALERT V1 in Milan

Efforts were accomplished to evaluate the impact of the wastewater quality on the correctness of the measurement performed by ALERT Lab, and to identify the location for the installation that would maximize the ALERT System's performance.

The ALERT Lab device did not exhibit any installation obstacle since the instrument performs the measurements on manually collected samples. The device allowed the concurrent measurement of E. coli and Total Coliform in six samples. However, manual operation was needed for sample collection, vials sterilization, sterilization of deionized water, sample dilution and reagent dosing. Cleaning procedure was necessary after every measurement, and it took approximately 15 minutes of manual washing with bleach followed by 20 minutes of sterilization with autoclave.

As concern Alert V1 tests, an installation point before the discharge would have been more suitable to guarantee a direct measurement of fecal contamination in the final effluent. However, the high turbulence in this point might hinder the good performance of the on-line analyzer (Figure 34). On the contrary, a sampling location placed before the UV disinfection unit showed suitable hydraulic condition for the on-line monitoring, although the measurements obtained in this point were not representative of the bacteriological quality of the discharged effluent, but only to the one upstream of the UV lamps. However, by knowing the bacteria removal efficiency of the disinfection process, it is still possible to estimate the bacteria concentration in the final effluent. For the above-mentioned reasons, the sampling location before the UV disinfection was chosen for the installation of the ALERT System V1 (Figure 33).

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Figure 34: sampling spot after the UV treatment

The ALERT System V1 tested in situ undoubtedly enhanced the degree of automation of the measurement performing bacterial quantification simultaneously in seven collected samples. The operator's effort diminished, and the amount of acquired data was increased. However, some manual procedures, such as vial sterilization, deionized water sterilization, and reagent dosing were still required. These procedures took several hours, and they needed the operator assistance. Furthermore, between two set of measurements, the suction pipe had to be carefully washed. Hence, the ALERT System's cleaning procedure was more onerous than expected and lasted longer than the cleaning procedure of the lab portable version. Finally, it is worth highlighting that the reagents had to be kept at low temperatures for long-term storage. It was a critical point to take into account during the warm seasons.

2.3.6. Installation, operation and maintenance of ALERT V2 in Milan

The ALERT V2 SYSTEM has been installed in Peschiera Borromeo WWTP from July 2021 to September 2021, and its outcomes were compared with laboratory determinations. Two separate monitoring campaigns have been performed during this period on Line 2 of the WWTP, where the sampling points were selected before the UV disinfection treatment.

Bacteriological analyses of wastewater samples by this on-line device were performed side-by-side together with microbiological analyses performed at the laboratory of CAP Holding. Particularly, when a sample was collected by the ALERT V2, at the same time one manual sample was collected and analyzed by the laboratory. The results elaborated by ALERT V2 were compared with those obtained by standard analyses in the laboratory (using membrane filtration and plating technique), to validate the Fluidion's measurement methodology.

A first validation campaign of ALERT V2 was carried out between July and August by performing 20 parallel analyses in the laboratory. A second monitoring campaign with ALERT V2 was performed in August – September with the same operating conditions but using two different types of cartridges.

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One set of cartridges was identical to the ones used in the first campaign with ALERT V2, the other set had an additional filter and check valve to be installed after the cartridges were placed inside the device.

Previous experience with ALERT V1 has provided useful knowledge to identify the best installation location that would maximize the ALERT performance. The installation of the ALERT V2 System has been addressed to the same location as the ALERT V1, namely the sampling location before the UV disinfection (Figure 35), because this location showed suitable hydraulic condition for the on-line monitoring. High turbulence present after the UV disinfection unit (Figure 34) created concern about the safe installation of the device, even though it would have ensured direct measurement of fecal contamination in the final effluent.

Figure 35: Installation of the Alert V2 at Peschiera Borromeo WWTP

The ALERT V2 device allowed the concurrent measurement of E. coli and Total Coliform in seven samples. The device did not exhibit any installation obstacle since the instrument performed the measurements in disposable cartridges easy to install. The only manual operations to be performed were the periodic change of the battery (Figure 37) and the insertion of the cartridges for the measurement (Figure 36). The procedure was simple and fast and could be done at once for the seven samples.

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Figure 36: Set up of the cartridges in ALERT V2

The new ALERT System has certainly overcome some of the issues faced with the previous version. Particularly, the enhanced degree of automation has strongly reduced maintenance operation.

Figure 37: battery replacement

2.3.7. Trouble shooting with ALERT V2 in Milan

The ALERT system V2 has however showed some issues related to communication reliability at the installation site, which were due to the poor reception inside the concrete well and to periodic GSM network outages. Due to these sporadic communication issues, the ALERT V2 installed at the Peschiera Borromeo WWTP still required operator assistance more frequently than expected (pulling out the device from the concrete well to re-establish network connection).

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2.4. Feedback on installation, maintenance and troubleshooting of Alert System V1 and V2

Overall, the most important difference between ALERT V1 and V2 are the efforts required to perform the maintenance procedures and redeploy the system. As described in Sections 2.1, 2.2 and 2.3, the ALERT V1 and V2 were installed and tested operationally by three independent operators in three different cities: SIAAP in Paris (France), KWB in Berlin (Germany) and CAP in Milan (Italy). The performed maintenance procedures by the three operators are comparable, and the conclusion is unanimous that the ALERT V2 is much easier to operate. Indeed, maintenance duration was reduced from 45-60 minutes to a few minutes. Additionally, the new disposable cartridge concept deployed in the ALERT V2 eliminates potential for human error, which had negatively affected both the reliability and the measurement accuracy of the ALERT V1, particularly in the lower concentration ranges. Indeed, the ALERT V2 has a metrological performance (accuracy, precision) that is similar, and in some cases superior to the laboratory (as documented in Section 3.1-3.3).

The ALERT V1 was installed in 2019 and 2020 in floating configuration at all three locations. No issues were encountered with the installation procedures, except for Milan, where it took some time to identify the means by which the system could be lowered into the concrete pit where it was finally deployed. The installation of the ALERT V2 was straight-forward in both Paris (rail installation) and Milan (floating installation similar to that used previously for the ALERT V1). In Berlin, the ALERT V2 system was used to perform a repeatability study in the laboratory, and it was installed on special stand on a bench top.

In terms of troubleshooting, it is notable that no operational issues were encountered with the measurements using the ALERT V2. Some communication issues were present, particularly in the Milan case, where the concrete pit reduced cell reception, and the network was unreliable, requiring some operator intervention to bring the system to the surface from time to time to regain connectivity for the cellular modem. If the system is to be installed in locations shielded from electromagnetic radiation, as was the case in Milan, it may be advisable to use an external antenna that is placed at surface would greatly improve reception and communication. Only two times (out of 70 measurements initiated) were observed connectivity issues in Paris that delayed the accomplishment of the automatic measurement. These experienced problems were partly due to network outage, and partly to a server issue. Overall, the ALERT V2 device could be deployed reliably at all locations, without any insurmountable issues, and the results are exploitable and rich in information.

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3. Sensor bias, precision and accuracy

Sensors data should be evaluated using simple and standard indicators in order to assess their reliability. Some characteristics of the sensors, such as the resolution and the working range, are available from the technical sheets. Standard indicators for sensors should be used not only to evaluate the "goodness" of the data provided, but also to make some considerations about their costs, their lifetime, their usability and the efforts required for their management.

The most common parameters used to evaluate the quality of the measurements are the resolution, defined as the minimum unit that the sensor can measure, the range, which includes the upper and the lower values that can be measured, and the accuracy.

From a functional point of view, external factors, and environmental and operative conditions, such as temperature, pressure and humidity, may affect sensors' reliability. The width of the ideal working ranges and the sensitivity to the variability of those operative parameters could be used as indicators of the robustness of the probe outputs and must be compared with the effective conditions that usually occur in the field. Thus, a standard procedure to detect sensors malfunction or outliers in the measurements need to be defined.

In this section are described all the experimental tests accomplished by DWC partners to assess uncertainty, precision, and accuracy of deployed sensors.

3.1. ALERT System and microbiological measurements

Standard procedures for the comparison of microbiological methods are briefly described in the following sections, in order to get a clear overview of the main methodologies currently used to compare two different methods. Finally, a method is proposed to assess the accuracy of the microbiological measurements performed by Alert devices.

3.1.1. Methods for comparison: ISO 17994:2014

The International Standard ISO 17994:2014 "Water quality – Requirements for the comparison of the relative recovery of microorganisms by two quantitative methods" reports a procedure to compare the results of two different microbiological analytical methods and can be applied for both the colony counts-based method and the MPN-based methods.

The preliminary phase of the comparison procedure consists in the establishment of a confidence interval. This interval is defined as a predetermined limit and its extension ranges from -2L to +2L. Concerning environmental waters, such as bathing waters, the ISO 17994:2014 proposes a predetermined limit of 2L = 20%. Here, L is defined as the smallest microbiologically significant mean relative difference.

Collected samples should be representative of the characteristics of the water source of the geographical and environmental area under investigation. Natural samples are preferred. However, appropriate samples may also be prepared by dilution, spiking, or mixing of different kinds of water to achieve the desired population in a suitable density. Spiking with pure cultures should be considered the last resort.

The most important basic requirement of comparison studies is a wide range of samples. Actually, there is no way to determine a priori the minimum number of samples required, since it depends on the differences measured, their standard variation and the chosen significance level.

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In general, it has been observed that the standard deviation of the mean relative difference should be less than 100. When it is used a 95% confidence limit, the number of samples required can be estimated as:

$$n = \frac{4s^2}{L^2} \quad (3.1)$$

n: number of samples required for the detection of a difference *L*;
L: smallest microbiologically significant mean relative difference;
s: experimental standard deviation.

Samples shall be excluded if both results are zero (0,0) or either method gives a non-countable result (e.g., TNTC, larger than, …). Outliers can be detected by plotting ln(a_i) against ln(b_i). If data are excluded, motivation should be explained.

The first step is to calculate the logarithmic values of the test results, in order to reduce the influence of concentration in the evaluation. After that, the difference between the logarithmic values is calculated. In this way the test variable *x* is obtained, representing the relative performance of two methods:

$$x_i = [ln(a_i) - \ln(b_i)] \times 100\% \quad (3.2)$$

When the results of one of the methods are zeroes, the relative differences are calculated, respectively in the case of pairs $(a_j; 0)$ and $(0;\ b_k)$:

$$x_j = ln(a_j + 1) \times 100\% \quad (3.3)$$

$$x_k = -ln(b_k + 1) \times 100\% \quad (3.4)$$

However, it should be preferred to obtain at least 75% of the samples containing regular count data from both methods.

The average relative performance $\overline{x}$ is estimated, according to the following formula:

$$\overline{x} = \frac{\sum x_i}{n} \quad (3.5)$$

n: number of samples;
x_i: relative difference in sample *i*.

The standard deviation of the mean relative difference (uncertainty) is calculated as:

$$s = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} \quad (3.6)$$

The standard uncertainty of the mean (formerly standard error) is expressed as:

$$s_{\bar{x}} = \frac{s}{\sqrt{n}} \quad (3.7)$$

The half-with of the confidence interval W is defined as:

$$W = \frac{2s}{\sqrt{n}} \quad (3.8)$$

Once all the parameters has been defined, the next step consists in the calculation of the limits of the confidence interval around the mean:

- Lower limit: $x_L = \bar{x} - W$ (3.9)

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– Upper limit: $x_U = \bar{x} + W$ (3.10)

Then, the comparison of the two methods can be performed.

a) The data are insufficient for a decision when: $x_L < -2L$ and $x_U > 0$ *or* $x_L < 0$ and $x_U > +2L$

In this case, additional samples are required and their number can be calculated using the following expression:

$$n = 4\left(\frac{s}{y}\right)^2 \quad (3.11)$$

n: number of samples required
s: standard deviation of the relative difference
y: max{ $\overline{x}$; | $\overline{x}$ | - | 2L |}
2L: predetermined stipulated limit from 0 in the case that the methods are not different in %;
$\bar{x}$: arithmetic mean of the relative difference in %.

b) Two methods are considered quantitatively not different if: $-2L \leq x_L \leq -2L$ *and* $0 \leq x_U \leq +2L$

This happens when the mean relative of the paired confirmed counts does not differ significantly from zero and the confidence interval does not extend beyond the level of the predetermined stipulated limit.

c) The methods are statistically different, but the difference is too small to be microbiologically significant when: $x_L > -2L$ and $x_U < 0$ *or* $x_L > 0$ and $x_U < +2L$

d) The methods are different when: $x_L > 0$ *or* $x_U < 0$

3.1.2. Methods for comparison: US EPA Site-Specific Alternative Recreational Criteria Technical Support Materials for Alternative Indicators and Methods

The US EPA Site-Specific Alternative Recreational Criteria Technical Support Materials For Alternative Indicators and Methods (USEPA, 2014) can be used to compare two methods through the definition of specific indexes or coefficients.

This procedure is specifically referred to ambient water and not to wastewater, but provide a simple methodology to evaluate if an alternative method can be used as a substitute of a standard one, for a specific site.

Environmental samples, representative of local conditions where the method will be applied, should be used, and at least 30 paired data are required.

Instructions for samples selection are specifically provided in the US EPA Site-Specific Alternative Recreational Criteria Technical Support Materials For Alternative Indicators and Methods (USEPA, 2014) documentation. If one of the paired measurements is below the limit of quantification or above the maximum level of detection, the coupled data should be removed. Outliers can be eliminated but must be justified.

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Data a_i and b_i from the two methods are first transformed in their respective logarithmic values x_i and y_i:

$$x_i = [log_{10}(a_i)] \quad (3.12)$$

$$y_i = [log_{10}(b_i)] \quad (3.13)$$

Then the Index of Agreement (IA) is calculated, varying from 0 to 1:

$$IA = 1 - \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}{\frac{1}{N}\sum_{i=1}^{N}(|x_i - \bar{x}| + |y_i - \bar{y}|)^2} \quad (3.14)$$

where

N is the total number of data points in the data set;
$\bar{x}$ and $\bar{y}$ are, respectively, the averages of the *x* and *y* data set.

The agreement of two methods is considered sufficient when IA ≥ 0.7.

If IA < 0.7, then the Pearson's correlation coefficient squared, R-squared, should be calculated. If the R-squared value is higher than 0.6, the alternative method can still be used, deriving new numerical limits through linear regression of the log-transformed data, in order to evaluate the geometric mean and the statistical threshold value.

3.1.3. Methods to assess the accuracy of ALERT data

For estimating the accuracy of measurements performed by ALERT devices, in this work were used the indications reported by the ISO 5725-1. The accuracy describes the combination of random and systematic errors. So high accuracy requires both high precision and high trueness (i.e. low bias).

Bias/Trueness

Bias/Trueness checks whether two measurement methods agree on average or whether there exists a systematic bias. If both methods agree, the average difference between paired samples should be zero. In microbiology, a log-normal distribution is a common assumption, so that the difference between a single pair i of measurements of ALERT and LAB samples is expressed on a log-scale, either by:

$$x_i = \ln ALERT_i - \ln LAB_i \quad (3.15)$$

or

$$x_i = \log ALERT_i - \log LAB_i \quad (3.16)$$

Using the natural log (ln) or log10 (log) is a matter of taste. The natural log is used in ISO 17994:2014 as an approximation of a percentage difference. The log10 may be preferred by others as it is commonly used to express concentration in microbiology.

The point estimate for the bias is calculated then by:

$$\bar{x} = \frac{\sum x_i}{n} \quad (3.17)$$

The calculated point estimate is subject to uncertainty. The 95 % confidence interval for estimating the bias can be readily calculated by:

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$$confidence\ interval\ (x_{Lower}, x_{Upper}) = \bar{x} \pm 1.96 * se \quad (3.18)$$

with *se*, which estimates the error on the bias, is calculated as:

$$se = \frac{sd}{\sqrt{n}} \quad (3.19)$$

Where the standard deviation, *sd*, is calculated as:

$$sd = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} \quad (3.20)$$

This procedure follows a classical paired t-test, as it is readily available by any statistical software.

It is important to note that the bias is normally calculated for repeated measurements of the same reference quantity, which is precisely known. In the case of microbiology, there are no concentration standards. Therefore, a measurement of bias can be performed by performing repeated measurements of E.coli concentrations in the same sample using two methods, one of which is considered the reference. The bias may depend on actual concentration (i.e. may not be a unique value across the full range of measurements), and should be evaluated at each relevant concentration. Bias measures the systematic errors produced by a measurement, method or instrument. Bias can generally be eliminated, e.g. through recalibration.

Trueness is a recently-invented term that is equivalent to bias. In the past, accuracy was used also as a synonym for bias/trueness, however the latest evolution of the metrology norms (ISO 5725-1:1994(en)) defines accuracy as the measure of total error, i.e. the total displacement of a result from a reference value, due to random as well as systematic effects.

A side note: since there is no reference standard in microbiology, bias measured between two methods can be introduced by either method especially if the reference method is a statistical (e.g. MPN most-probable number) and not an absolute method (e.g. membrane filtration or flow cytometry).

Precision

Precision in metrology refers to the variability between different measurements of the same specimen. The ISO 5725-1:1994 standard further specifies:

“Many different factors (apart from variations between supposedly identical specimens) may contribute to the variability of results from a measurement method, including:

1. the operator;
2. the equipment used;
3. the calibration of the equipment;
4. the environment;
5. the time elapsed between measurements.

The variability between measurements performed by different operators and/or with different equipment will usually be greater than the variability between measurements carried out within a short interval of time by a single operator using the same equipment.

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The general term for variability between repeated measurements is precision. Two conditions of precision, termed repeatability and reproducibility conditions, have been found necessary and, for many practical cases, useful for describing the variability of a measurement method. Under repeatability conditions, factors 1) to 5) listed above are considered constants and do not contribute to the variability, while under reproducibility conditions they vary and do contribute to the variability of the test results. Thus repeatability and reproducibility are the two extremes of precision, the first describing the minimum and the second the maximum variability in results. Other intermediate conditions between these two extreme conditions of precision are also conceivable, when one or more of factors a) to e) are allowed to vary, and are used in certain specified circumstances. Precision is normally expressed in terms of standard deviations."

In statistics, the precision may be defined as the reciprocal of the variance and refers to the

$$precision = \frac{1}{\sigma^2} \quad (3.21)$$

In practice, the precision is simply assimilated to the standard deviation of repeated measurements of the same sample. Sample homogenization is a critical aspect of such a test, since the bacterial concentrations measured on different aliquots of a sample may be quite different. Samples can be homogenized very effectively in small volumes. Larger volumes, however, may be quite inhomogeneous (e.g., due to sedimentation or difficulty of providing sufficient mixing energy) and therefore introduce significant errors.

In DWC precision is addressed in the replication study in Berlin:

a. within - ALERT - repeatability based on repeated measurements

- Repeated measurements of same sample with ALERT-Lab and ALERT-System at seven concentration levels spiked with WWTP secondary effluent. σ, σ^2 of obtained measurement at each concentration are calculated.

$$sd_{ALERT} = sd(\log ALERT_i)) \quad (3.22)$$

b. within - laboratory - repeatability

- Repeated measurements of same sample at 2 difference laboratories at seven concentration levels spiked with WWTP secondary effluent. σ, σ^2 of obtained measurement at each concentration are calculated.

$$sd_{Lab,i} = sd(LAB_i) \quad (3.23)$$

Weakness of the proposed approach

A potential weakness of the proposed approach in (Angelescu et al., 2019) is that the ALERT System was calibrated using the protocol for surface water. Thereby, the observed variability of lab results follows the "*within-lab-variability*" of the surface water protocol, which is considerably larger than the variability of the bathing water protocol. It seems plausible that if the bathing water protocol was used for calibration, the observed variability could be lower. Then, the derived threshold would be higher.

Moreover, the two labs included in the study were located in Paris and Lyon. Thus, the "*between-lab-variability*" might be increased because of the distance between the cities (5h by car).

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Both the surface water protocol used and the distance between labs (i.e., very different times to transport samples to the lab) contribute to an increased variation. Due to the low number of laboratories the true "*between-lab-variability*" remains highly uncertain. The study of the information about the between-lab-variability (difference in means) is missing.

3.2. Online sensors for water quality monitoring

Raw data from the monitoring network of meters and sensors require to be elaborated in order to extract accurate results from data-driven analysis. Data analyses need to be implemented using knowledge and characterization of WWTP-specific process. Nowadays many data from WWTPs are available thanks to technology progresses and the spreading of a wide network of sensors and meters. However, these data are still widely underutilized in part due to a lack of background knowledge in the field of data science, and in part due to issues related to the non-stationary working operations of WWTPs (Newhart et al., 2019).

3.2.1. Bias calculation and evaluation of data quality

Sensor performance can be evaluated using different statistic parameters, such as accuracy, precision, bias, trueness, repeatability, long-term stability, reproducibility, response time, calibration uncertainty, non-linearity, measurement noise, coefficient of variation, and limit of detection and quantification, as suggested by (Samuelsson, 2017). Standards methods to evaluate sensors performance are defined in the ISO 15839:2006 "Water quality – On-line sensors/analysing equipment for water – Specifications and performance tests" (ISO 15839:2006, n.d.) and in the UNI EN 17075:2019 "Water quality – General requirements and performance test procedures for water monitoring equipment – Measuring devices", which include recommendations for validation under both laboratory conditions (without disturbances) and full-scale condition. However, as reported in literature (Samuelsson, 2017), the full-scale validation procedures are more of a general guideline, since they strongly depend on local measurement conditions. Normal conditions are vaguely defined, due to the high variations in wastewater characterization that regularly occur in the plant. Only large errors that significantly differ from the "normal" distribution can be easily detected, since faulty distributions have potentially a large overlap with the normal trend. Moreover, the location of the sensor in the plant layout also affects the measurement variations.

In the present work, sensors data were compared with laboratory measurements to evaluate the bias produced by on-line measurements. Sensor data were pre-processed before the bias calculation. Particularly, outliers, missing data, and periods with flat sensor measurements were detected and removed.

Samples for ordinary laboratory analyses were based on a composite 24-hour collection (the composite collection started at 10:00 a.m.). Thus, sensors' data measurements were daily averaged to be comparable with laboratory measurements. Furthermore, the limit of quantification of laboratory analyses was higher than the detection limit of probes measurements. Hence, a further threshold was applied on data collected by probes imposing the lower measured value equal to the quantification limit of the lab measurements to obtain comparable data. Then, the relative error of the sensor measurement was calculated by the difference between the daily average of sensor data and the lab measurement (i.e., considered as the "true value"), which was divided by the lab measurement.

$$Prob_{error} = \left|\frac{P_i - O_i}{O_i}\right| \times 100 \quad in \ (\%) \tag{3.24}$$

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where subscript i refers to the daily-averaged measurement, $P\ and\ O$ stand for the recorded value by the prob (predicted) and at the laboratory (observed), respectively. Finally, a mean sensor error was calculated by averaging the relative errors calculated by Eq. (3.24).

Cecconi et al. (2019) calibrated the probs only when the difference between the sensors' reading and lab analysis was around 20% ultimately. For the lower range of difference, they did not implement any sample adjustment. Accordingly, in this study, we selected the validity threshold of prob data as 20% (i.e., if $Prob_{error} > 20\%$, the daily-averaged measurement exceeds the acceptable error).

3.2.2. Methods for real-time outlier identification

Outliers are data points that significantly deviate from the normal trend available in the data points. The outliers can be originated from different sources among their measurements and recording errors are of great importance in WWTPs. The existence of outliers may transfer a wrong message to the data analysts, so it is recommended to recognize and delete them in the preprocessing phase of data analytic. Based on the recognition technique, the outlier detection methods can be categorized into statistical-based, distance-based, clustering-based, and density-based methods (Smiti, 2020). In statistical methods, an outlier is a data point that does not follow the governed standard distribution. They can be parametric or non-parametric methods. The parametric methods are well suited to the data points with known distribution; however, non-parametric approaches successfully dealt with the dataset with unknown distribution. Although the statistical-based models perform fairly well when the distribution is known, their functionality is under debate (regarding the computational cost and accuracy) in the case of large datasets or high dimensional cases. Furthermore, they cannot be implemented into the data points with unknown distribution (Smiti, 2020).

In this report, the performance of conventional statistical approaches such as Hotelling's T-square, sliding window techniques such as Moving Average Absolute Deviation (M-AAD), Moving Median Absolute Deviation (M-MAD) as well as two innovative methods, developed in this study, including Moving Standard Absolute Deviation (M-SAD) and integrated MSAD-Tsquare are evaluated in recognition of the outliers in the prob records. Figure 38 illustrates the various steps that must be fulfilled to assess the accuracy of different outlier detection approaches. As shown, first, the daily-averaged values of instantaneous prob measurements, i.e., not-cleaned data, are calculated and the errors between the daily-averaged prob measurements and their correspondent lab values are calculated based on Eq. (3.24). The mean of these errors will give a mean error for not-cleaned data. Then, the not-cleaned data are fed into the outlier detection method, and so the outliers are recognized and deleted (hereafter cleaned data). After deleting the outliers, the daily-averaged values of cleaned data are calculated and the error between daily-averaged cleaned data and the correspondent lab measurements are calculated based on Eq. (3.24).

It should be noted that when the averaged values of probs values were less than the lower detection limit of lab measurements, they were considered equal to the respective detection limit.

Two criteria are exploited to measure the outlier detection method accuracy (1) the number of daily-averaged measurements whose error (calculated based on Eq. (3.24)) exceed 20%, and (2) mean prob error before and after outlier deletion (cleaning process).

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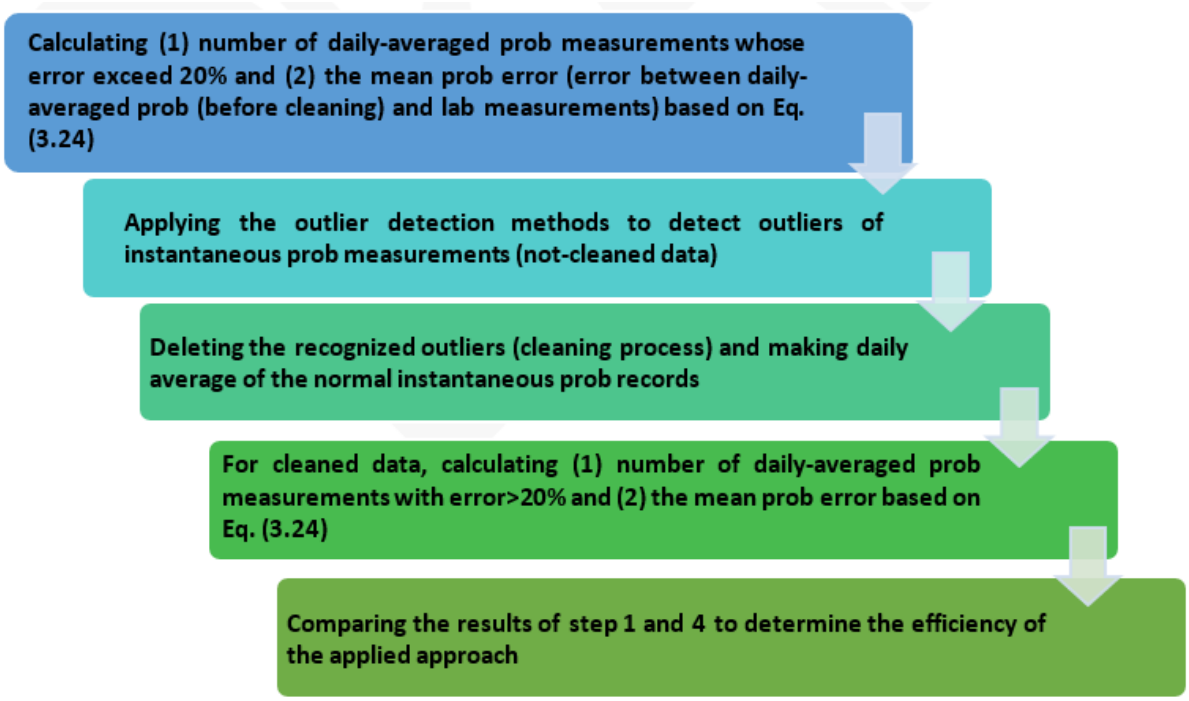

Figure 38: Procedure for the evaluation of the accuracy of the various outlier detection methods

Moving Methods

Traditional outlier detection methods consider the whole data points and calculate the residuals (the difference between prob data points and correspondent lab values). They can be positive or negative depending on whether the prob value is greater than or less than the lab value. Various statistics are then calculated on the residuals, and these are used to identify and screen outliers.

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Table 17 summarizes some traditional outlier detection methods with their definition.

For clear explanations, below "**Mean and Standard Deviation Method**" are explained in detail. For the normally distributed dataset (in which median and mean are the same), 99.7% of the data ranges between -3σ and $+3\sigma$, where σ is the standard deviation of data points as defined in Eq. (3.25):

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i-\mu)^2}{N}} \qquad (3.25)$$

in which σ stands for the standard deviation, subscript i refers to the index of a datapoint, x is the value of datapoint, μ stands for the mean of data points, and N is the total number of data points.

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Table 17. Traditional outlier detection methods

Method	Description
Mean and Standard Deviation Method	Returns true for elements more than three standard deviations from the mean. This method is faster but less robust than 'median'. This method can fail to detect outliers because the outliers increase the standard deviation. The more extreme the outlier, the more the standard deviation is affected.
Median and Median Absolute Deviation Method (MAD)	Returns true for elements more than three scaled MAD from the median. The scaled MAD is defined as: $$MAD(X) = co * median(\lvert x_i - mdeian(X)\rvert)$$ Where x_i refers to an optional instantaneous prob measurement and X stands for the total instantaneous prob records. The coefficient $co = 1.4826$ for normal distribution (see section 5.2.3 for detailed explanation). Accordingly, the MAD without any multiplication actor reads as $MAD(X, 1) = median(\lvert x_i - mdeian(X)\rvert)$. This method is generally more effective than the mean and standard deviation method for detecting outliers, but it can be too aggressive in classifying values that are not extremely different. Also, if more than 50% of the data points have the same value, MAD is computed to be 0, so any value different from the residual median is classified as an outlier.
Median and Interquartile Deviation Method (IQD)	Returns true for elements more than 1.5 interquartile ranges above the upper quartile or below the lower quartile. This method is useful when the data is not normally distributed. This method is somewhat susceptible to influence from extreme outliers but less so than the mean and standard deviation methods. Box plots are based on this approach. The median and interquartile deviation methods can be used for both symmetric and asymmetric data.

Considering the normal distribution, only **0.3%** of data points are not in the range of -3σ and $+3\sigma$ (Figure 39) which are assumed as outliers. In other words, if $\boldsymbol{M_i} = \frac{x_i - \mu}{\sigma}$ is larger than three, the considered data point will be an outlier. This method suffers from various deficiencies as below:

- In many cases, the data distribution is not Normal.
- This method considers the whole population while the outliers may place in local extremes.
- The potential outliers affect the standard deviation and mean values of data points. Hence, the results are biased in the case of outliers with large values.

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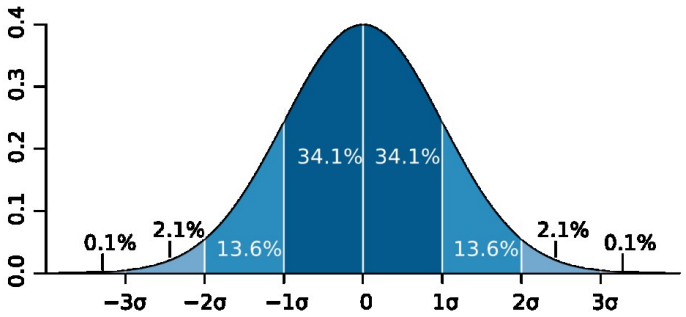

Figure 39. Data percentage in different ranges of standard normal distribution

To compensate for the above-mentioned limitations, it is suggested to implement the standard deviation criterion into a sliding window (Hochenbaum et al., 2017). To detect anomalous points in time series, a **Sliding Window Technique (SWT)** is one of the powerful methods due to its applicability for real-time detection (Kulanuwat et al., 2021). Moving window methods are ways to process data in smaller batches at a time, typically to statistically represent a neighborhood of points in the data. The moving average is a common data smoothing technique that slides a window along with the data, computing the mean of the points inside of each window. This can help to eliminate insignificant variations from one data point to the next. The size of this window must be determined based on the trial-and-error process.

3.2.3. Moving Average Absolute Deviation (M-AAD)

One alternative for traditional outlier detection methods is an approach based on Moving Average Absolute Deviation (M-AAD) proposed by Hochenbaum et al. (2017) as follows.

To detect the outliers using this method, the following steps must be fulfilled based on M-AAD:

1. Determine a window size based on a trial-and-error process (to this goal, one can examine the performance of the M-AAD for different window sizes based on a benchmark dataset). In this project, we examined the effects of various window sizes on the accuracy of the results (see section 3.2). The most optimal window size results in cleaned daily-averaged data which are less biased from the lab measurements.
2. Calculate the Moving mean (M_{mean}) for each window following equation (5.26). It returns a vector with the same size as the investigated dataset. For example, for the calculation of the first component of moving mean of a vector ($Mmean_{i=1}$) with predefined window size, one must consider the first window components ($x_{i \in win=1}$) and calculates their mean ($mean(x_{i \in win=1})$).

   $$Mmean_i = mean(x_{i \in win}) \quad (3.26)$$

3. Calculate Moving Average Absolute Deviation (M-AAD) of datapoints located at each window based on Eq. (4). It should be noted that M-AAD returns a vector of the same size as the data points. For instance, to calculate the first component of M-AAD vector ($MAAD_{i=1}$), one must consider the data points located in the first window ($x_{i \in win=1}$) and calculate their mean ($M_{win=1}$). The average deviation of the absolute difference between $x_{i \in win=1}$ and $M_{win=1}$ will give $MAAD_{i=1}$. Other components of MAAD are calculated considering the datapoints of consecutive windows.

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$$MAAD_i = mean(|x_{i\in win} - mean_{win}|) \quad (3.27)$$

4. Calculate **modified Z-score** denoted by M_i for each data point following equation (3.28).

$$M_i = \frac{|x_i - Mmean_i|}{co \times MAAD_i} \quad (3.28)$$

where co is a specified constant. It should be noted that co calculates based on total prob instantaneous records while $Mmean$ and $MAAD$ are calculated within the considered window. Since the number of windows equals the number of instantaneous prob measurements, $Mmean$ and $MAAD$ return vectors whose size is the same as the data points. Finally, in the calculation of M_i, x_i is the prob record in the total data points and in this stage the windows are not applied anymore.

Under an assumption of Gaussian distribution associated with the data, the value of co can be derived as $co = \frac{1}{Q(0.75)} = 1.4826$ (Leys et al., 2013). The reason for considering the constant c=1.4826 is to put MAD on the same 'scale' as the sample standard deviation for large normal samples. For instance, consider a normal distribution of 1000 observations with mean value $\mu = 100$ and standard deviation $\sigma = 15$. The calculated MAD for such a dataset is 10.1176; hence, $co = \frac{std(X)}{MAD(X,1)} = \frac{15}{10.1176} = 1.4826$ as expressed above. Exploiting this concept, in this project in which the instantaneous prob measurements do not have a normal distribution, co is calculated for different parameters following the ratio between standard deviation and MAD of total measurements. Table 18 summarizes the different values calculated for co in different parameters.

5. If M_i is larger than 3, the considered data point (x_i) is an outlier. Otherwise, the data point of interest is normal. Indeed, the application of co factor to probe data tries to make the trend of the sensors data distribution like that of normal distribution. Thus, outliers are identified when their value is 3 times std far from the mean value.

Table 18: co coefficient calculated for different parameters

	NH_4	TSS	NO_3	PPO_4
$co = \frac{std(X)}{MAD(X)}$	1.3246	1.5421	1.6071	1.7916

Moving Median Absolute Deviation (M-MAD)

To detect the outliers using this method, M_i is calculated based on the following equation:

$$M_i = \frac{|x_i - Mmedian_i|}{co \times MMAD_i} \quad (3.29)$$

where

$$Mmedian_i = median(x_{i\in win})$$

$$MMAD_i = median(|x_{i\in win} - median_{win}|) \quad (3.30)$$

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Hence, a moving median is calculated within the sliding windows. The same co coefficient calculated in Section 5.2.3 can be used herein this method. Finally, criteria to detect outliers are the same of those described in previous paragraph.

3.2.4. Moving Standard Absolute Deviation (M-SAD)

This approach is an innovative outlier detection approach developed in this study. Similar to previous sections, the following steps must be fulfilled to detect outliers based on moving standard absolute deviation (M-SAD):

1. Determine a window size based on a trial-and-error process (to this goal, one can examine the performance of the M-SAD for different window sizes based on a benchmark dataset). In this project, we examined the effects of various window sizes on the accuracy of the results (see section 5.3). The most optimal window size results in cleaned daily averaged data which are less biased from the lab measurements.
2. Calculate Moving Standard deviation (M_{Std}) for each window following equation (5.31). It returns a vector with the same size as the investigated dataset. For example, for the calculation of the first component of moving standard deviation of a vector ($Mstd_{i=1}$) with predefined window size, one must consider the first window components ($x_{i\,\in\,win=1}$) and calculates their standard deviation ($std(x_{i\,\in\,win=1})$).

$$Mstd_i = std(x_{i\,\in\,win}) \tag{3.31}$$

3. Calculate Moving Standard Absolute Deviation (M-SAD) of datapoints located at each window based on Eq. (9). It should be noted that M-SAD returns a vector of the same size as the data points. For instance, to calculate the first component of M-SAD vector ($MSAD_{i=1}$), one must consider the data points located in the first window ($x_{i\,\in\,win=1}$) and calculate their standard deviation ($\sigma_{win=1}$). The standard deviation of the absolute difference between $x_{i\,\in\,win=1}$ and $\sigma_{win=1}$ will give $MSAD_{i=1}$. Other components of MSAD are calculated considering the datapoints of consecutive windows.

$$MSAD_i = std(|x_{i\in win} - \sigma_{win}|) \tag{3.32}$$

4. Calculate **modified Z-score** denoted by M_i for each data point following equation (3.33).

$$M_i = \frac{|x_i - Mstd_i|}{co \times MSAD_i} \tag{3.33}$$

where co is a specified constant. If M_i is larger than 3, the considered data point (x_i) is an outlier. Otherwise, the data point of interest is normal.

3.2.5. Hotelling's T-square Method

Although SWTs resulted in acceptable predictions, their functionality mainly depends on the window size and outliers' value. In other words, one of the most important challenges regarding this method is the size of the sliding window. If we choose a very small window size, the global outliers may not be recognized well. The more is the window size; the more is the possibility to lose the local outliers.

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As an alternative, Principal Component Analysis (PCA) can be exploited for outlier detection. PCA decreases the dimensions of datasets in a way that their interpretability increases. To do this, PCA maximizes the variance of datasets by mapping them in a new coordinate (new uncorrelated variables). The most correlated parameters are deleted while information loss is minimum. The proposed method was limited to up to three parameters; however, in 1933 Harold Hotelling described the methods for computing multivariate PCA.

To detect the outliers, the data points are converted in an ellipsoidal coordinate with a predefined radius knwon as alpha in this report. The data points outside the ellipsoid are outliers while the data points inside the ellipsoid are normal data. In the case of normal distribution, the radios (alpha) will be 1 which detects around 98% of data points as normal data. However, alpha can vary based on the distribution of data of interest. Following a similar trend, in this report we calculated alpha in a way that the ellipsoide contained 95% of probe data points (normal data). To do this, varios values ranged from 0.5 to 10 with step 0.1 were examined.

The performance of the T-square method is severely dependent on the number and value of data points. To avoid losing local outliers, in this study, we adjusted the same concept as the “sliding window technique” for the T-square method. Accordingly, first, instantaneous prob measurements are divided into several classes (i.e., groups of data) considering their acquisition period. The number of most optimal classes is determined based on the trial-error process from a predefined range.

3.2.6. Integrated M-SAD and T-squared

The T-squared method detects outliers based on the predefined radius in each class. The predefined radius equals one in the case of the normally distributed dataset, but for non-normal distributions, like the prob measurements in this project, it can be determined based on the trial-error process. The distribution of the data imported into the T-squared method for outliers’ detection is very important in the determination of sphere radius. The existence of a large outlier may inhibit the model from correct detection of local outliers in the vicinity of large outliers. In other words, the T-square method is more affected by the outliers placed in the vicinity of minimum extreme. Contradictory, the M-SAD approach is very inclined to capture the outliers located in the vicinity of maximum extreme. Hence, to overwhelm these limitations, a new integrated algorithm that exploits both the M-SAD and T-square approaches is devised in the current study. To detect the outliers using this integrated tool, the following steps must be fulfilled:

1- Make instantaneous prob measurements daily-averaged and calculate the error between daily-averaged prob measurements and their correspondent lab values using Eq. (3.24). This will give (1) the number of daily-averaged records with errors of more than 20%, and (2) mean prob error before cleaning.
2- Select a moving window size for outlier detection based on the trial-error process: in this study, several window sizes are implemented and the most optimal one is selected based on (1) the number of data with prob error more than 20% and (2) mean prob error before and after cleaning process.
3- Implement the M-SAD approach to the not-cleaned data and detect outliers. As expressed in Section 2.1.1 the outliers are data points whose modified z-score exceed 3.
4- Delete the detected outliers.
5- Import the cleaned data into the T-square method and detect the rest potential outliers (second cleaning process): It should be noted that in this study, the optimal radius of the T-square method (alpha) and the number of classes are determined following a smart trial-error

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process. We assumed a range for the possible number of classes. i.e., 1 to 58. The performance of the method (based on the rate of reduction in a number of the data with errors more than 20% and the mean prob error measurements) is evaluated for all the class numbers. The most optimal class number results in more accurate daily-averaged prob measurements. In each class, the optimal alpha is a value that detects less than 5% of the class data points as an outlier.

6- Make second-cleaned prob measurements daily-averaged and calculate the error between them and their correspondent lab values using Eq. (3.24). Again, this will give (1) the number of daily-averaged records with an error of more than 20%, and (2) mean prob error after cleaning.
7- Use the number of data whose error is more than 20% based on Eq. (3.24) and mean prob error before and after cleaning (calculated in steps 1 and 6) to evaluate the efficiency of the method.

This method considers the data points which are located beyond a predefined diameter (threshold) by the user (for normally distributed data points, it is around one) or their modified z-score is more than three as outliers. In this approach, there are two phases: (1) first T-square and M-SAD methods are separately used to recognize the outliers of total data points. To do this, first, whole data points are imported into M-SAD and their outliers deleted, and then the cleaned data is fed into the T-square method for outlier determination; (2) The cumulative outliers recognized by both the models are outliers of the integrated model. The concept of this algorithm is due to the weakness of the T-square method in the recognition of high-value outliers. In many cases, the T-square method does not consider high-value data points as an outlier but in fact, they are outliers. To avoid this problem, we implement a double-check process using the standard deviation method which outperforms other methods in the determination of high-value outliers. Figure 40 illustrates the various steps that must be fulfilled in the integrated method for the detection of outliers. In this figure, the data accuracy refers to the number of daily-averaged prob measurements whose value exceed 20% and the mean daily-averaged prob errors (based on Eq. (3.24)).

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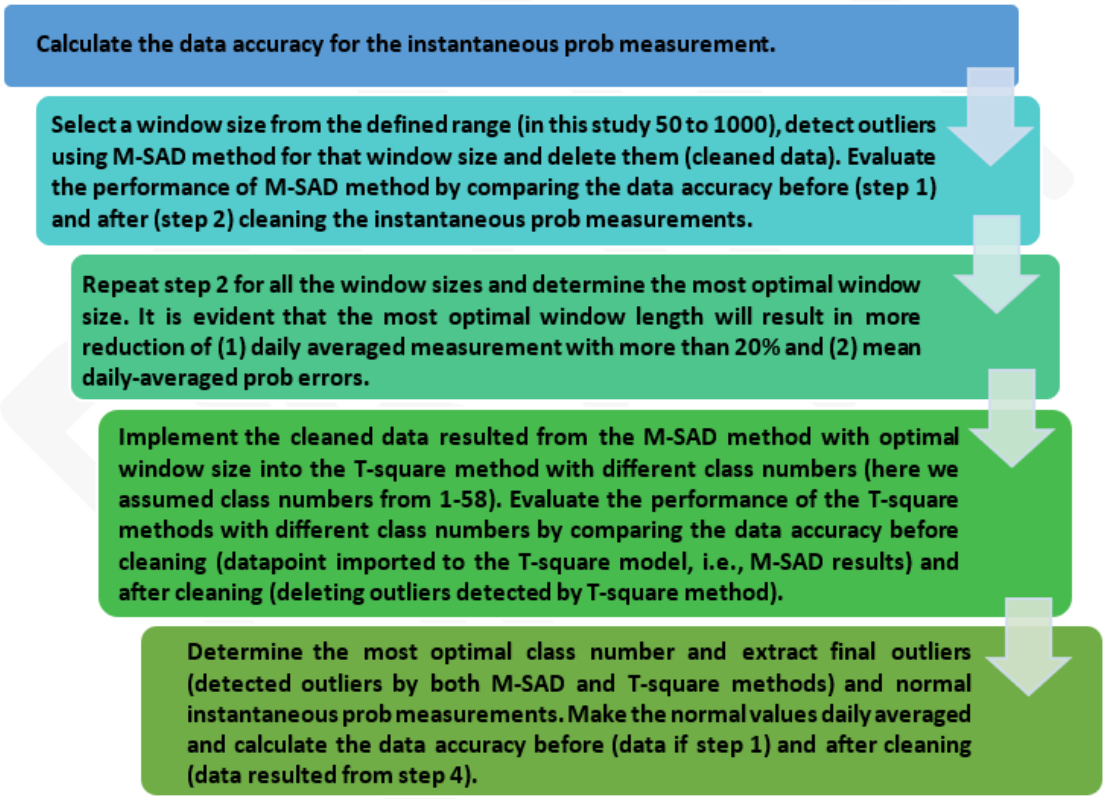

Figure 40. Procedure for the evaluation of the accuracy of the various outlier detection methods

3.3. Data analysis of ALERT systems

ALERT devices were utilized to monitor the bacteriological contamination of two bathing waters and of a treated wastewater, which can be used for agricultural reuse. In all the case studies in DWC project, bias, precision and accuracy of ALERT systems were evaluated.

3.3.1. Demo-case in Paris with ALERT V1: Surface water and storm water study

To accomplish the comparison of ALERT data with laboratory measurements, only synchronous data were considered. To take into account the synchronization problems between Alert and automatic samplers, the data retained are those with less than 1-hour difference between the two systems. This issue was not relevant for sampling in networks and for the spatial characterization measurement campaigns.

On these bases, the graph in Figure 41 was obtained. Data are well differentiated between:

- Measurements in natural environment (Seine-Alma & Marne)
- Measurements on the Saint-Baudile.

The data collected cover a wide range of concentrations and the relationship between the two methods appears to be significative.

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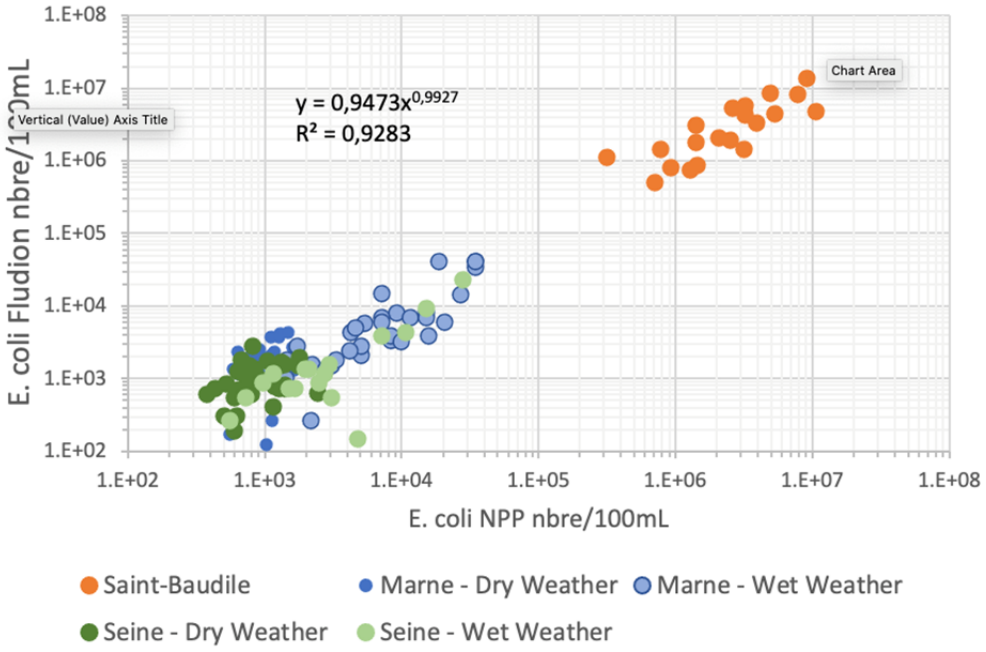

Figure 41: Comparison between ALERT and laboratory data for all combined deployments in Paris area (including surface water during dry and wet weather, as well as stormwater outflow monitoring)

The coefficient of determination for the data in Figure 42 reaches 0.9, which indicates the presence of a good correlation between data measured in the laboratory and by Alert Lab.

It is important to note that laboratory measurements use only 2 ml of samples while Fluidion uses 25 ml. The larger sample quantity of ALERT means that we can expect the results to be more representative of water quality. However, the use of such a large amount of sample may result in the presence of aliquots. This may overestimate the amount of E.coli in the water.

Moreover, only the free-floating bacteria is accounted for by the laboratory through the MNP micro-plate technique, while the ALERT system measures the full bacterial load.

Using the previously-reported reference procedures to compare microbiological methods (Sections 3.1.1, 3.1.2 and 3.1.3), ALERT data were evaluated against lab measurements for all surface water (Seine and Marne river) measurements (Figure 42 and Figure 43). 87 side-by-side measurements pairs were used.

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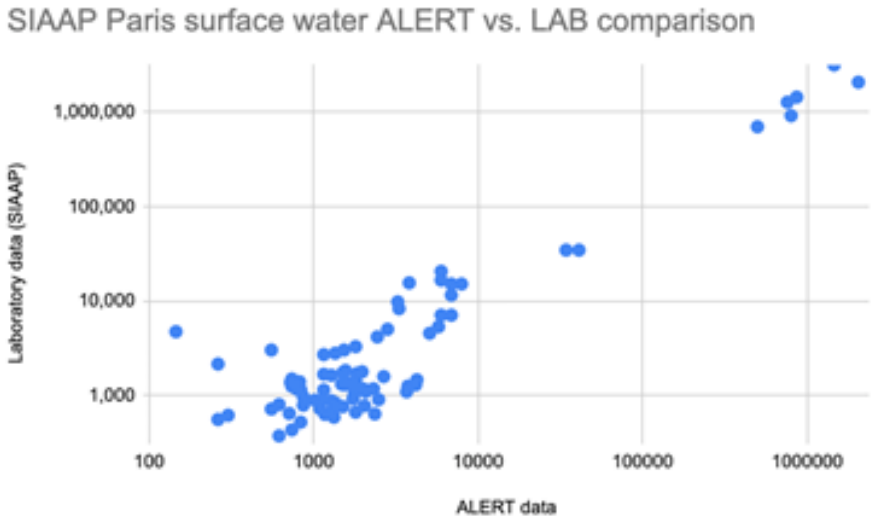

Figure 42: Lab vs Alert data in Paris sampling campaign (restricted to surface waters)

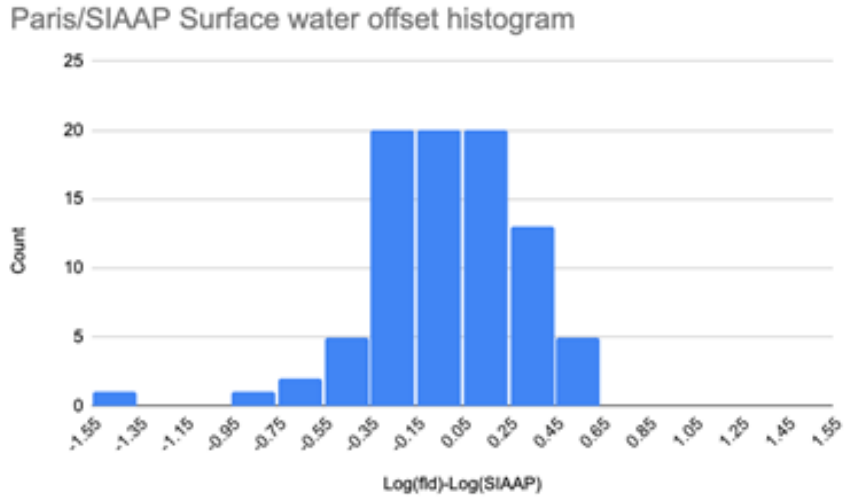

Figure 43: Lab-Alert offset in Paris sampling campaign (restricted to surface waters)

The bias was calculated to be -0.029 $\log_{10}$ units. The precision, calculated over the full concentration range, was 0.34 $\log_{10}$units.

According to the ISO 17994:2014 for the Paris case study, and using L=10%, the following parameters were calculated:

$\bar{x}$= -6.57%
s = 77.39%
$\bar{s}$= 8.30%
$W = 16.59\%$
$x_L = -23.16\%$
$x_U = 10.02\%$

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Since x_L < -2L, the result of the comparison is inconclusive and further measures are required. We do notice however that the condition is almost satisfied (and if L=12%, the condition is satisfied), whereas the condition $W > \bar{x}$ is clearly satisfied, so it is reasonable to expect that additional data would make the comparison fully satisfied according to the ISO 17994:2014.

Considering the US EPA comparison method and the calculation of the Index of Agreement, it was obtained:

$$IA = 0.96 > 0.7$$

Thus, the comparison between Alert data and laboratory data is satisfied according to the value of the IA.

3.3.2. Demo-case in Paris with ALERT V2: Surface water and storm water study

The data measured at Ablon in 2021 consisted of a time-series collected over two months of deployment. Several rain events were recorded over this period, and were sampled with the ALERT V2, however the sampling for side-by-side measurements was only performed at a fixed time once a week, so all the rain events were actually missed by the laboratory. In total, 9 manual samplings were performed, and 8 side-by-side usable points were collected (on July 13, 2021, a communication issue due to cell network outage prevented the ALERT V2 from being activated at the same time as the manual sample). Hourly rainfall information was also available for Orly (source: SIAAP), which is the closest city that confluence with the Orge river upstream of Ablon. These data were deemed to be relevant for the pollution observed at Ablon, and therefore their impact on the *E.coli* measurements should be investigated. The time series data is presented in Figure 44 below.

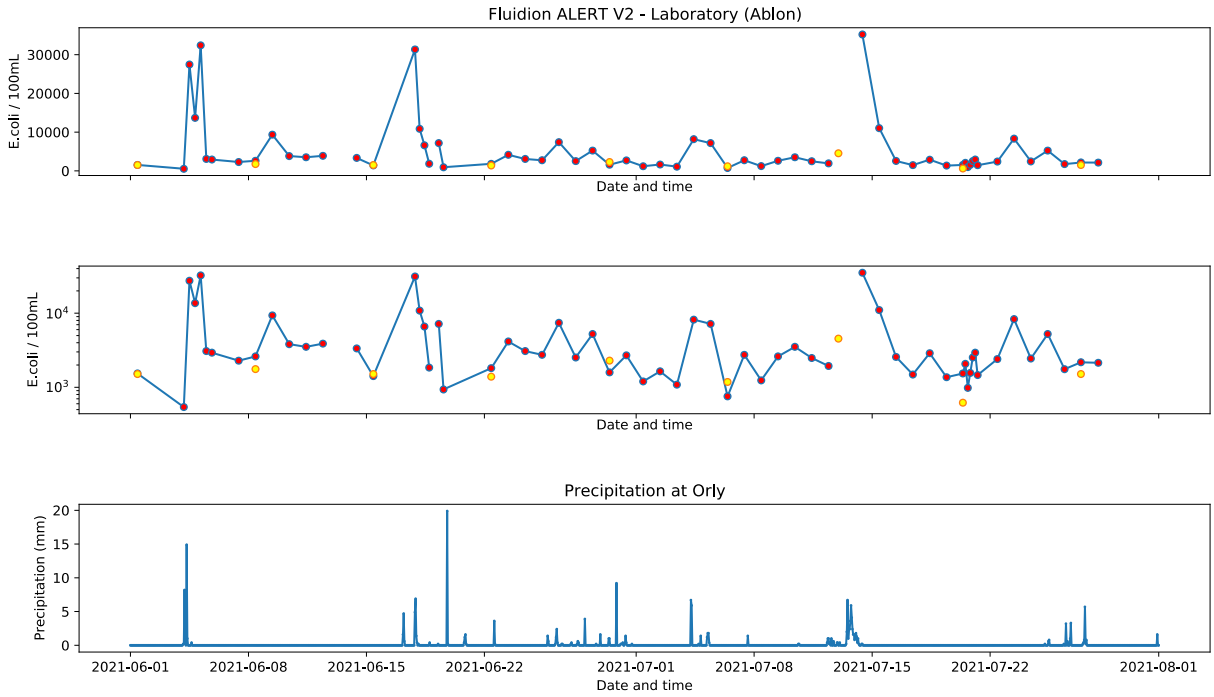

Figure 44: The ALERT V2 time series (red) and laboratory data (yellow) collected at Ablon during the 2021 campaign. Top panel shows the bacterial concentration data in linear scale, the middle panel in log scale. The bottom panel displays the hourly rainfall.

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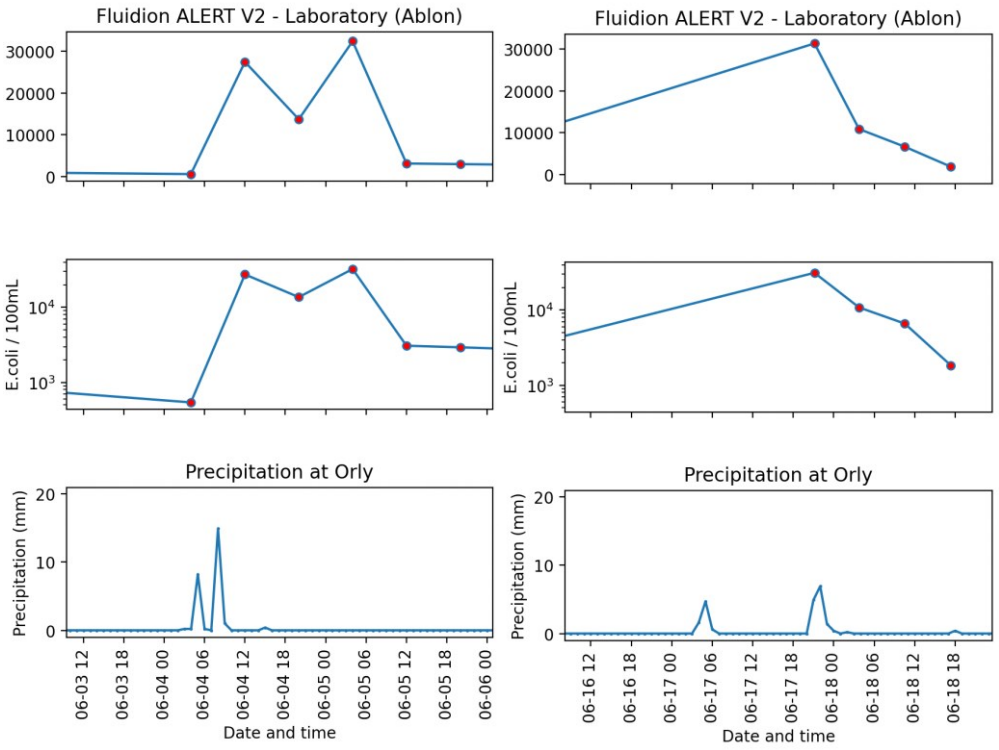
As it appears from the data, a good correlation can be established between the rainfall at Orly and the observed bacterial peak measured by the ALERT V2 at Ablon. Indeed, all the bacterial peaks were correlated with rain events, and displayed on the four 60-hour zoom panels in Figure 45. It can also be observed that the peak for bacteria concentration is observed very soon after the start of the rain, less than eight hours for the major pollution event that happened on June 4th, which could be recorded in its entirety, and only 4-5 hours for the smaller pollution event on July 4th. This confirms the fact that the observed pollution is directly related to rain events in nearby Orly. From these data it can also be inferred that the Ablon site takes approximately 24-30 hours to clean up after such a rain-water pollution event.



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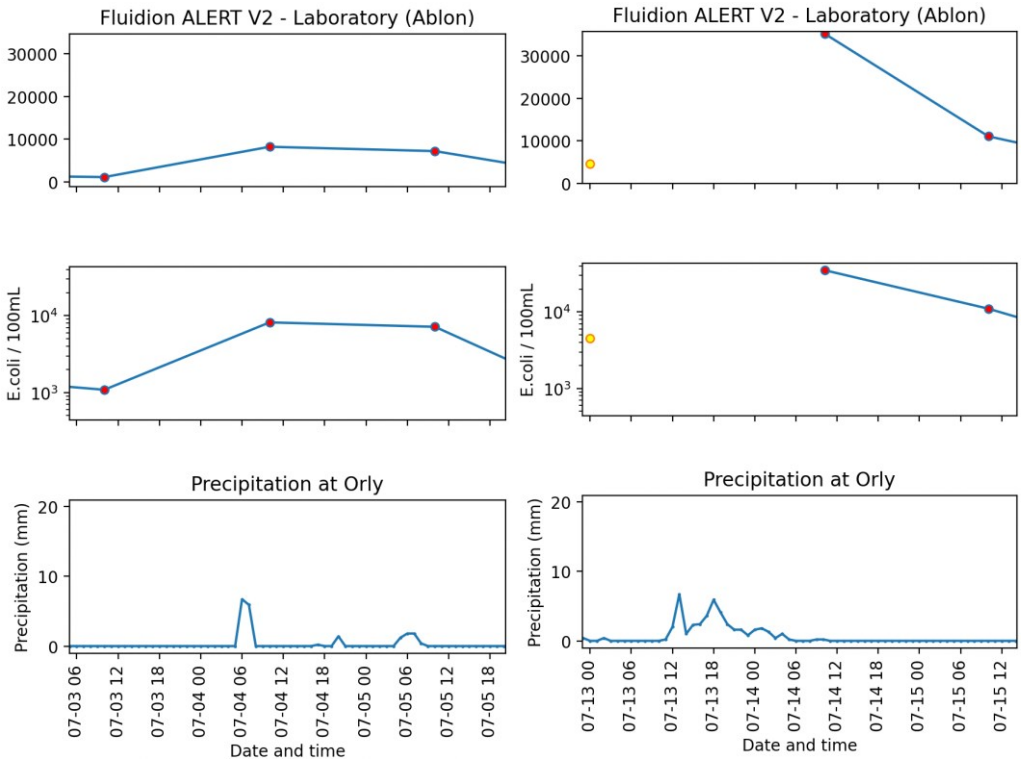

Figure 45:60-hour zoom panels of the four larges bacterial peaks observed during the 2-month campaign at Ablon.

The data acquired during the 2021 campaign also allows to follow the evolution of the water quality during the 24-hour dry-weather sampling campaign performed on July 20th (Figure 46).

Interestingly, the diurnal variation shows peaks at 12:45pm and at 02:45am. The minimum concentration was recorded at 16:15pm. Given the 4-5 hour approximate transit time for bacteria to travel from Orly (inferred from the wet weather pollution peaks), these diurnal peaks would correspond to peak pollution produced around 7:45-8:45am and 9:45-10:45pm. Interestingly, this corresponds to the periods of maximal water use by the population while at home for taking showers and also for toilet use (July 20 being working day). Therefore, these pollution peaks could be attributed either to direct, untreated sewage outflows from such activities, likely due to illegal sewage discharges. While this interpretation provides a very tempting explanation for the observed behavior, it is highly speculative. Positively confirming this hypothesis would require significantly more high-frequency monitoring in dry weather.

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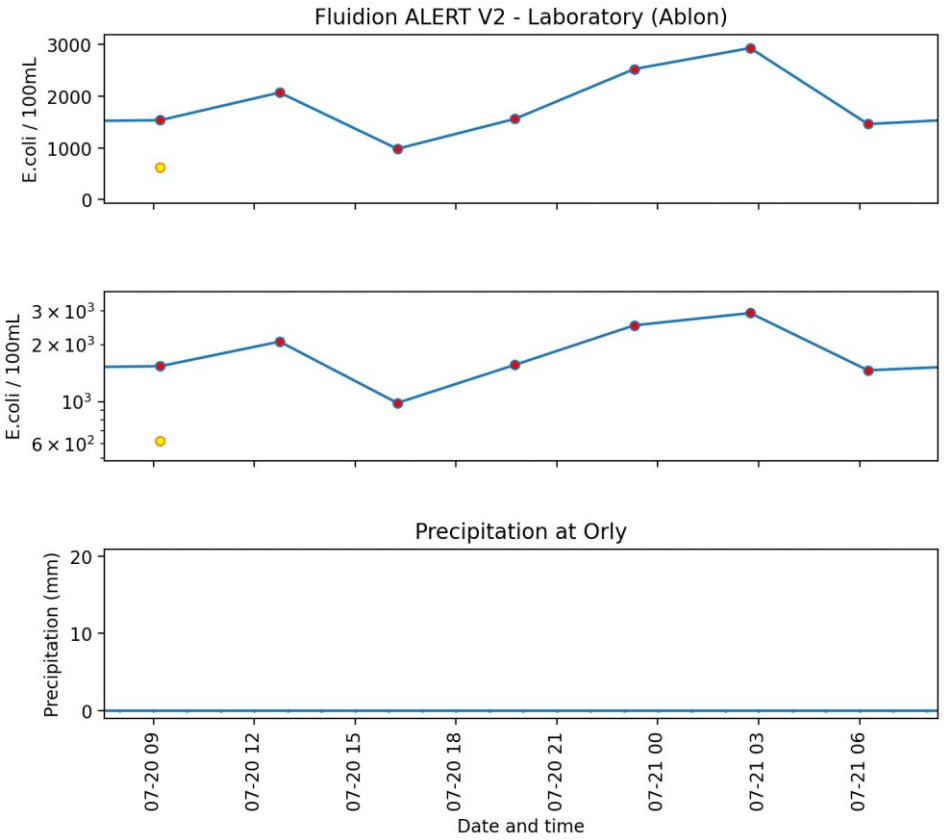

Figure 46: High-frequency 24-hour dry-weather sampling campaign (3.5 hours sampling interval).

Finally, the side-by-side data was used to compare the ALERT V2 measurements with the approved laboratory measurements performed on samples collected at the same moment. The results, shown in Figure 47 and Table 19, indicate an excellent agreement between the laboratory and ALERT V2. Indeed, the bias of the ALERT V2, calculated from these data, is measured at only 0.058 $\log_{10}$ units. Furthermore, since three of the laboratory measurements indicated exactly the same value (3.179 $\log_{10}$ units), they can be used to infer the precision of the ALERT V2 measurements, calculated as the standard deviation of the respective ALERT V2 values: 3.187, 3.151 and 3.338. The in-situ precision of the ALERT V2 at Ablon is therefore measured at 0.099 $\log_{10}$ units, which is coherent with the precision assessed from the repeatability study, which measured between 0.077 $\log_{10}$ and 0.166 $\log_{10}$ units in this range of concentrations (Table 19).

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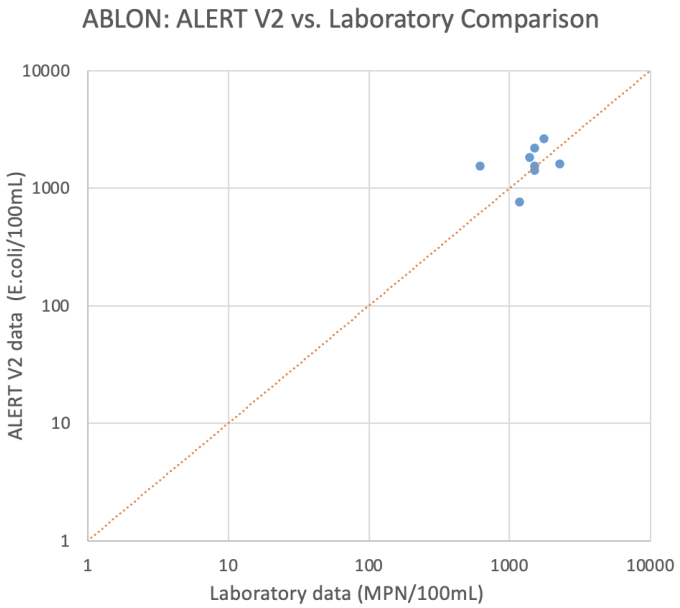

Figure 47: The side-by-side data comparison for Ablon

Table 19: The side-by-side laboratory and ALERT V2 data (the base-10 logarithm is shown), and the observed deviation.

Side-by-side comparison (Ablon)		
Log 10 ALERT V2	**Log10 Lab**	**Log difference**
3.187	3.179	0.008
3.417	3.246	0.171
3.151	3.179	-0.028
3.259	3.143	0.116
3.201	3.360	-0.159
2.877	3.072	-0.195
3.187	2.792	0.395
3.338	3.179	0.159

3.3.3. Demo-case in Berlin with ALERT V1: Canal water study

Even for the case study in Berlin, ALERT data were compared to laboratory measurements. Using the previously reported reference procedures to compare microbiological methods (Sections 3.1.1 and 3.1.2), ALERT data were evaluated against lab measurements (Figure 48 and Figure 49), where side-by-side measurements pairs were used.

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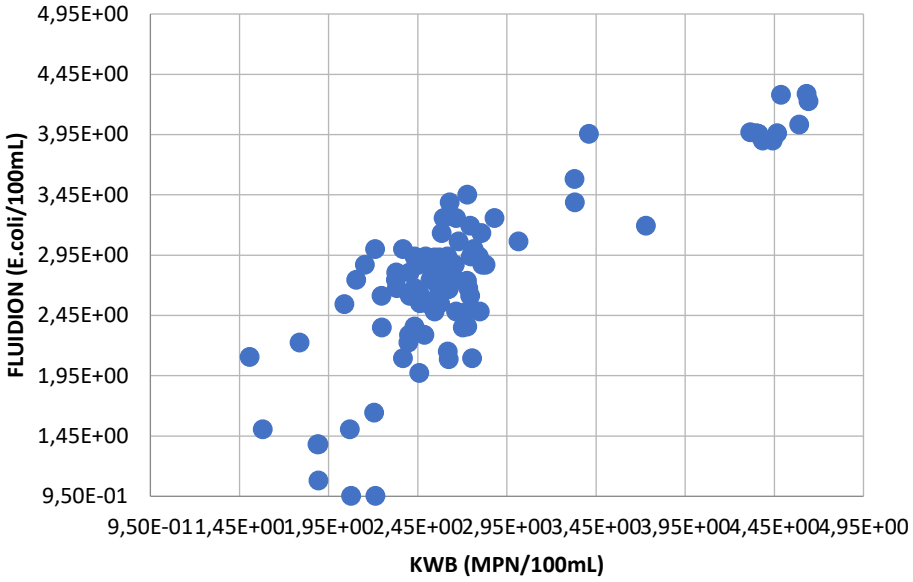

Figure 48: Lab vs Alert data in the Spree River sampling campaign

The correlation coefficient (R) for the data in Figure 48 is 0.8, the bias -0.10 $\log_{10}$ units, and the precision (calculated as standard deviation of the log differences) is 0.58 $\log_{10}$ units.

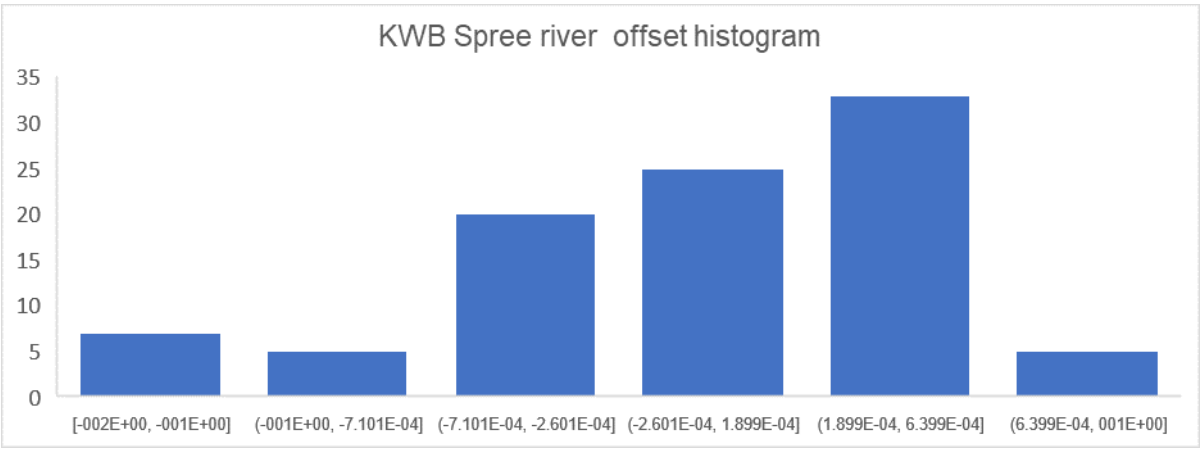

Figure 49: Lab-Alert offset in Berlin sampling campaign

According to the ISO 17994:2014 for the Berlin case study, and using L=10%, the following parameters were calculated:

$\bar{x}$= 6.93%
s = 102.25%
$\bar{s}$= 10.49%
$W = 20.98\%$
$x_L = -14.05\%$
$x_U = 27.92\%$

The result of the comparison is inconclusive and further measures are required.

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Considering the US EPA comparison method and the calculation of the Index of Agreement, it was obtained:

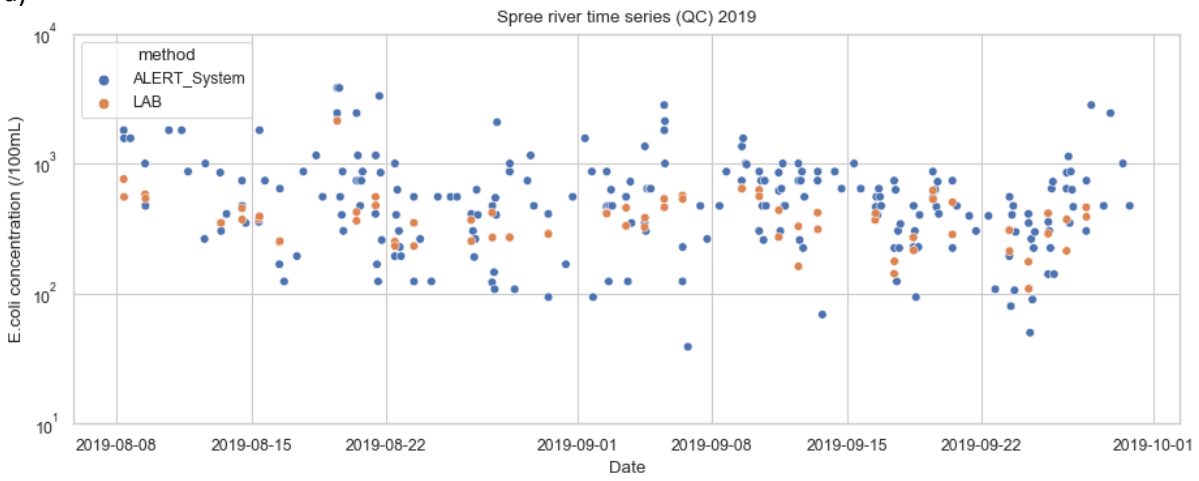
$$IA = 0.90 > 0.7$$

Thus, the comparison between Alert data and laboratory data is satisfied according to the value of the IA.

In the case study of Berlin, a much deeper investigation was accomplished to evaluate the accuracy of data obtained by sensor devices. The results from the Spree canal side-by-side sampling campaign are shown in Figure 50, Figure 51 and Figure 52. The concentration range is mainly between 10^2-10^3 *E.coli* per 100mL for the lab data, as exceptionally almost no rain events occurred during 2019 or 2020 (with the exception of three successive rain-related contamination events at the end of the 2020 sampling period). The time series recorded in 2019 and 2020 are shown in Figure 50 a-b. We observe that the ALERT and laboratory measurements follow very similar trends. ALERT shows a number of low measurements in 2020 (possible outliers), especially at lower concentrations, which were not observed in 2019. This is likely, as discussed further below, the result of disinfectant left in the sampling tubes during the maintenance. It is plausible that a small amount of disinfectant left behind after maintenance could remove a small quantity of bacteria, which would be more visible at the lower concentrations studied. This could be due to a slightly different maintenance procedure used between 2019 and 2020 (such as a flushing/rinsing step after disinfection that is too short).

At the end of the 2020 sampling season (zoom in Figure 50c), we observe three distinct contamination events, where laboratory samples read consistently above 1000 MPN/100mL. All three contamination events were detected reliably by both ALERT Lab and ALERT System devices (on the third contamination event, the ALERT System was not installed, so only ALERT Lab detected it). This proves the ability of ALERT technology to rapidly detect contamination events that could place bathers at risk.

a)



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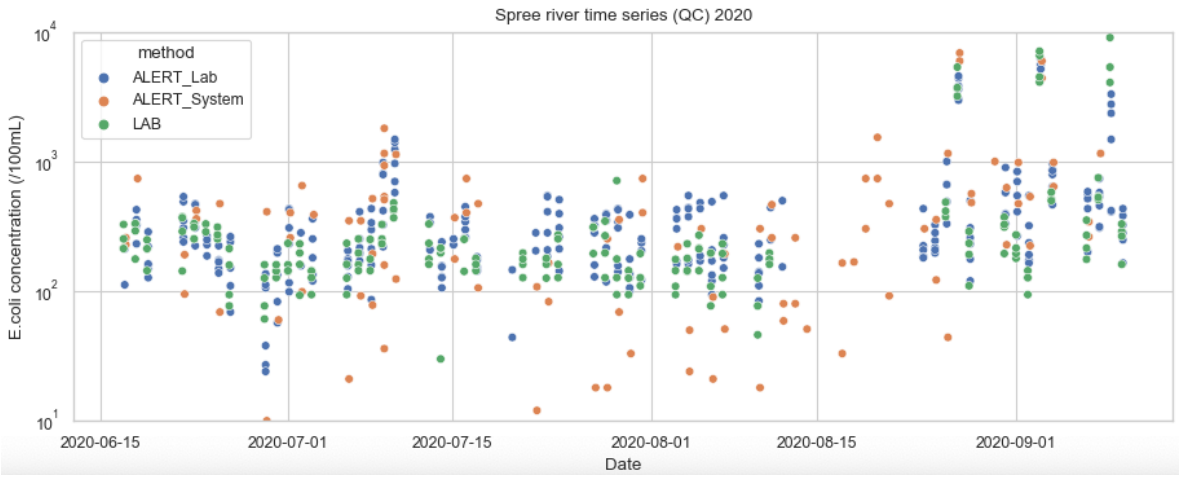
b)



c)

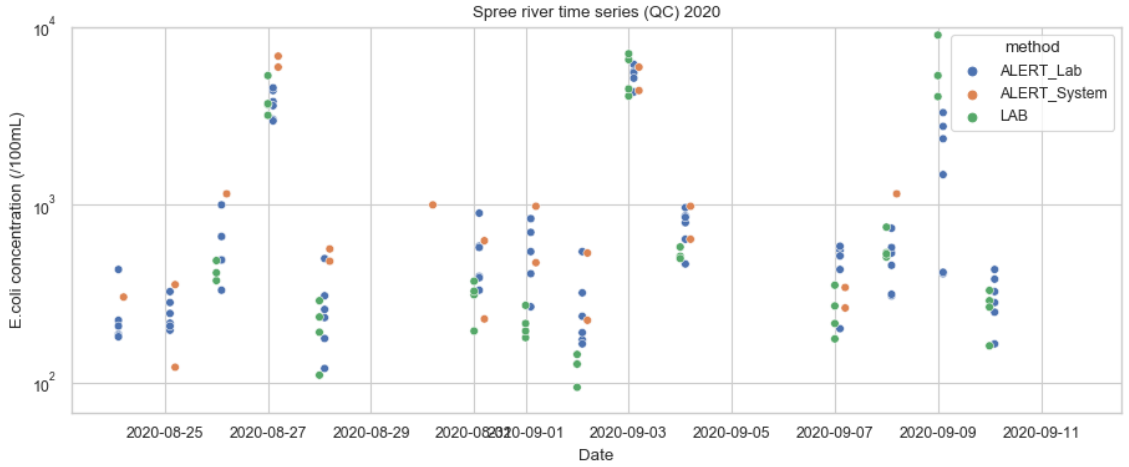


Figure 50 - The comparative time series recorded at the Spree canal a: In 2019 (using ALERT SYSTEM and laboratory data); b: In 2020 (using ALERT SYSTEM, ALERT LAB and Laboratory data); c: Zoom on the three contamination events observed on August 27 and September 3, 9 2020).

The ALERT Lab shows a constant overestimation bias (0.12 $\log_{10}$ units or 32%) in comparison to the laboratory data. Neither the bias, nor the standard deviation show a relevant concentration dependency. Interestingly, this bias completely disappears when the ALERT Lab TC data (after transport, storage and cooling) are compared to the lab data (Figure 36). The disappearance of the bias for ALERT LAB TC samples (after transport and cooling) may be caused by multiple effects including the degradation of *E.coli* during storage, and the overall lower sample temperature, which potentially leads to a delayed fluorescence and thus to lower ALERT measurements. To separate these effects additional experiments would be necessary. However, it is important to note that the ALERT technology was originally calibrated with samples that were cooled prior to analysis (similar to the ALERT LAB TC samples) so it is not surprising that the ALERT LAB TC data matches the laboratory perfectly (bias: 0.03-0.05 $\log_{10}$ units, approximately 7-10%).

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In 2019 the ALERT System in Canal Spree showed a bias of + 0.18 $\log_{10}$ units (95% confidence limits: 0.1 – 0.26) for the side-by-side comparison with the laboratory (i.e. the ALERT system measures on average 0.18 higher than the lab). In 2020, the bias was lower at 0.03 $\log_{10}$ units (95% confidence limits: - 0.07 – 0.13). If both years combined, the bias becomes 0.09 $\log_{10}$ units (95% confidence limits: 0.03-0.16). From Figure 36 (row 2) it can be seen that the bias depends on the concentration due to the presence of some low-concentration outliers (see below) which reduce the otherwise constant bias observed with the ALERT lab.

The precision of the ALERT Lab is better than the one of the ALERT System: the standard deviation between duplicate ALERT Lab measurements was 0.28 $\log_{10}$ units, while between duplicate ALERT System measurements it was 0.39 $\log_{10}$ units in 2019 and 0.66 $\log_{10}$ units in 2020 (the 2020 degradation is due to the presence of a few outliers at low concentrations, discussed above). The difference in precision between ALERT Lab and ALERT System is due to the variability introduced by the maintenance operations through possible residues of disinfectant product, as described above and elsewhere. For comparison, the precision of the laboratory can be similarly estimated from the standard deviation between duplicate laboratory measurements: 0.20 $\log_{10}$ units. The actual precision of each method can be calculated by dividing the standard deviation by $\sqrt{2}$, which is due to the quadrature addition of the independent log-normal variables represented by each measurement.

In 2020, the precision degradation of the ALERT System is more pronounced, presumably because the overall concentration level is lower than in 2019, and possibly because of a different maintenance routine between the two bathing seasons. As briefly discussed above and more at length in the repeatability study below, precision degradations are primarily visible at lower concentrations which are vulnerable to potential residues of disinfectants present in the sampling tubes after maintenance of the device. Such low concentration levels are not directly relevant for bathing water management. Accuracy and precision are most important at concentration levels between 500 – 2000 MPN/100 mL for bathing water quality management, depending on the threshold applied for decision-making, and in this concentration range (500-2000 MPN/100mL) the ALERT System has better precision than at the lower concentrations and reliably detect contaminations at higher concentrations, as shown in Figure 52c.

By the development of the V2 of the ALERT system, which replaces the manual maintenance and disinfection procedure, with a more reproducible cartridge system, further improvement of the precision is expected. Additional investigations that confirm this point were performed in 2021.

At the higher concentrations measured during the sampling campaign, which are of high concern for bathing water monitoring, the data from the 2019 and 2020 Spree canal studies show that both the ALERT System and the ALERT Lab show high agreement with the reference laboratory results. Although the total number of contamination events in the collected time series is low, the results indicate the suitability of ALERT technology to reliably detect such contamination.

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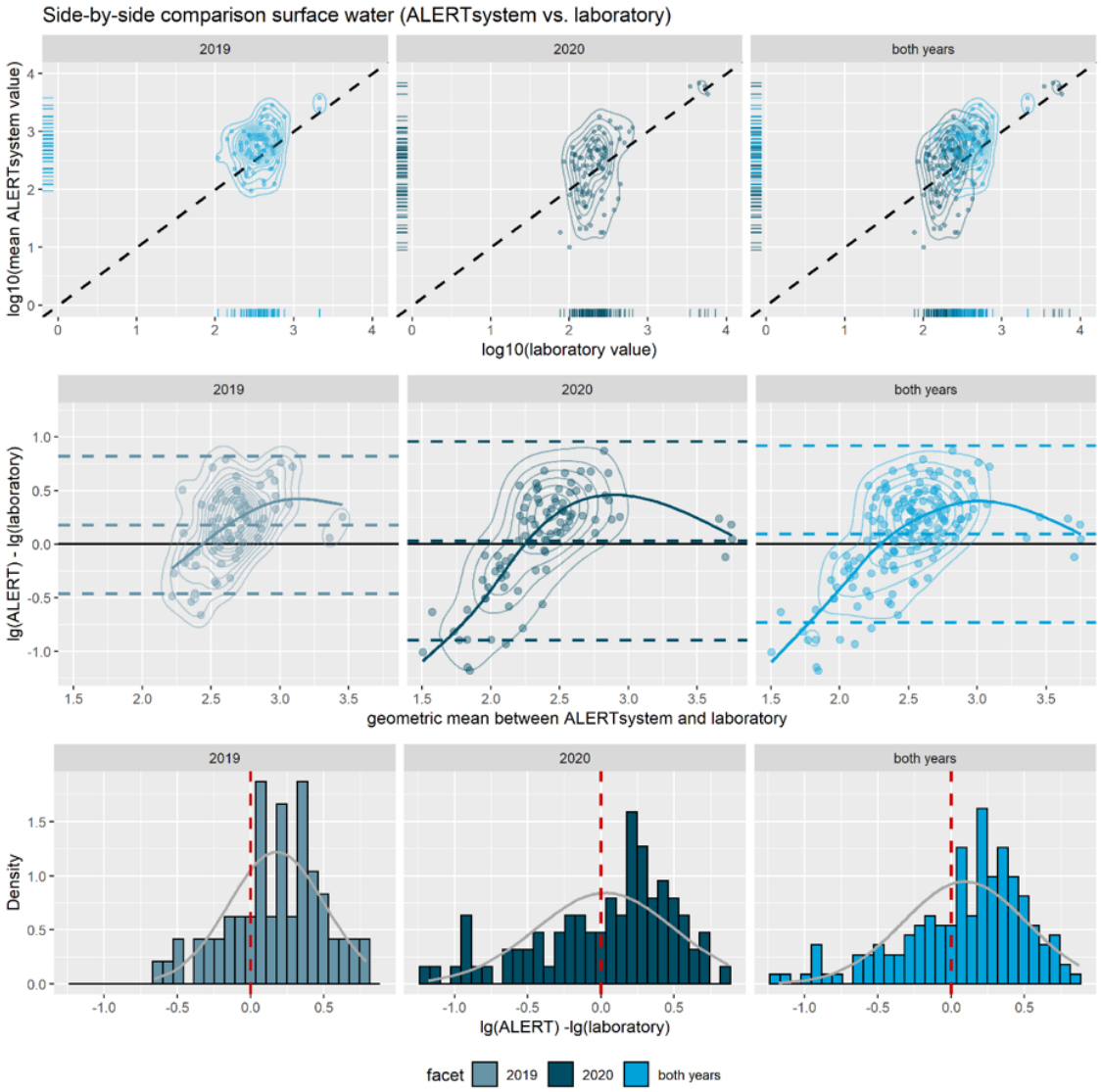

Figure 51: Laboratory vs. ALERT system: (from top to bottom): x-y plot + 2d-density, Bland Altman plot + 2d-desnity trendline fitted with generalized additive modelling, histogram of residuals (red line: mean of 0)

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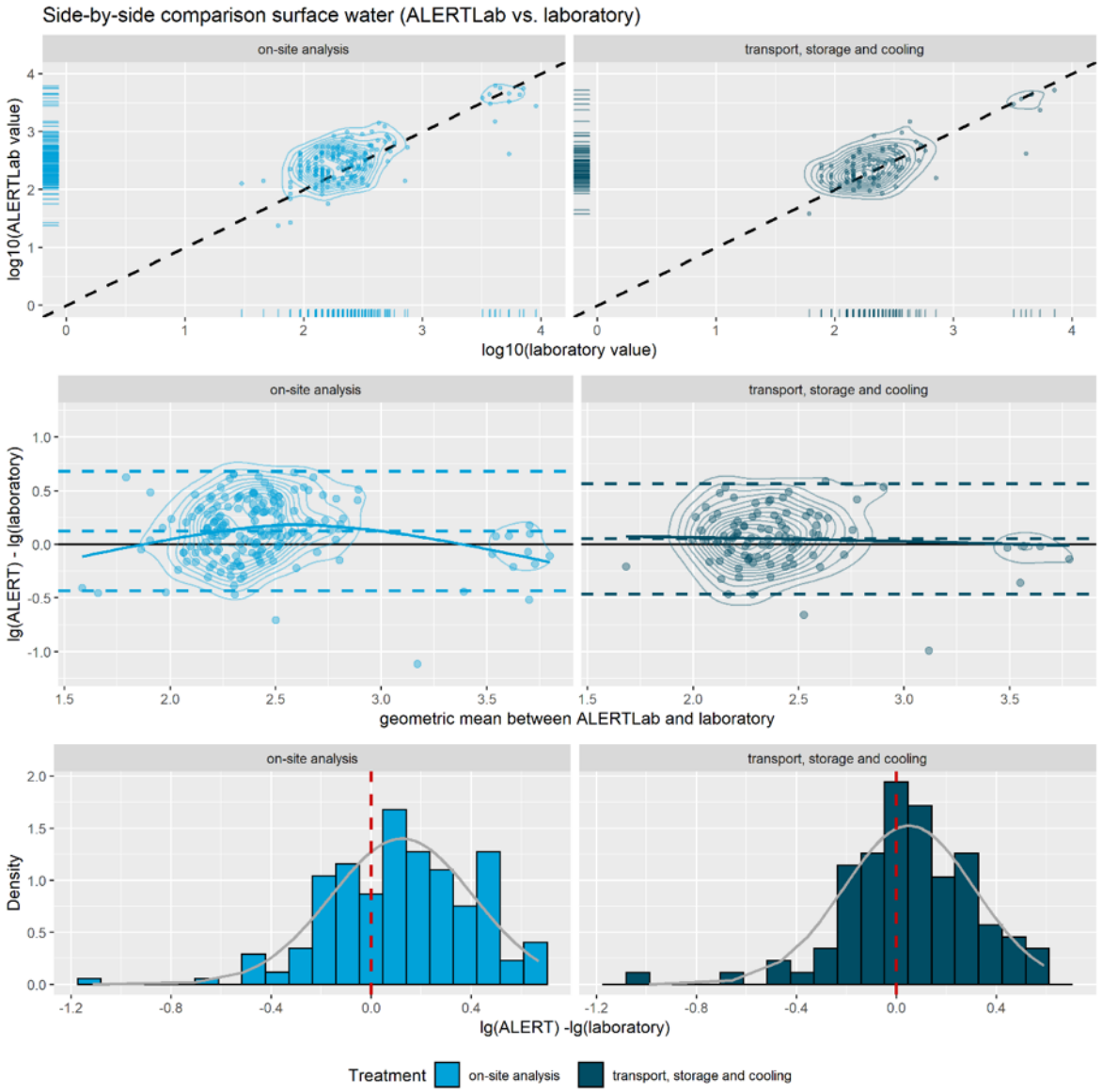

Figure 52: Laboratory vs. ALERT Lab: left (from top to bottom): x-y plot, histogram of residuals and Bland Altman plot before transport, storage and cooling. Right: x-y plot, histogram of residuals and Bland Altman plot after transport and cooling. Points represent the mean of duplicate samples.

Repeatability study 2020

Figure 53, Figure 54 and Figure 55 summarize the main results of the replication study conducted in Berlin. The results show that the two independent laboratories show high agreement in both the location of the mean as well as regarding the level of precision at the different concentration levels. The ALERT Lab shows a comparable level of precision as the two laboratories. However, the results from the ALERT Lab show a systematic bias towards higher concentrations (of 0.12 $\log_{10}$ units, or 32%) in comparison to the laboratory results, over the full concentration range. The systematic nature of the bias of the ALERT Lab shows that it can easily be corrected by applying a constant correction factor.

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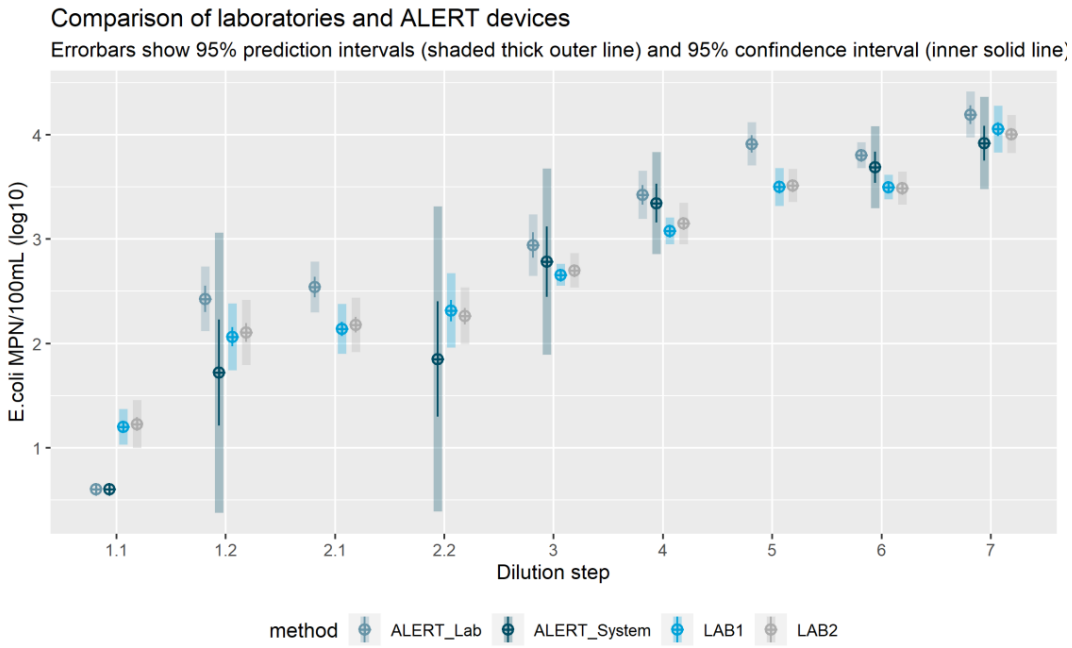

Figure 53: Replication study results. The plots show the individual measurements of the two accredited laboratories (LAB1, LAB2) (N = 12) and the two ALERT devices (ALERT_Lab, ALERT_System) (N=6, N = 7)

This high precision of the ALERT Lab, moreover, proves the repeatability of the ALERT measuring technology. The reason for the 32% overestimate could be related to multiple causes:

1. ALERT technology measures ALL bacteria present in a sample, including bacteria present on particles or clumps of bacteria, whereas the MPN reference method is unable to measure particle-bound bacteria. Even though the WWTP effluent sample was filtered at 5µm, the pore size is sufficiently large to allow clumps of 2 to 3 bacteria to pass through (typical E.coli dimensions are 2µm long by 0.5µm in diameter). This could account for the overestimate by ALERT Lab.
2. The ALERT technology was calibrated using samples collected in the field, transported to a laboratory in a cooler, and stored in a fridge prior to starting the laboratory analysis (at the same time as the ALERT measurement). The sample history is similar to the ALERT Lab TC treatment described above, but different to the field-measured ALERT Lab samples. This further corroborates with the fact that ALERT Lab TC samples from the Spree river study do not show practically any bias (0.03-0.05 $\log_{10}$ units, or about 7-10%). Potential explanations about the measurement differences between ALERT Lab and ALERT Lab TC samples were presented above.

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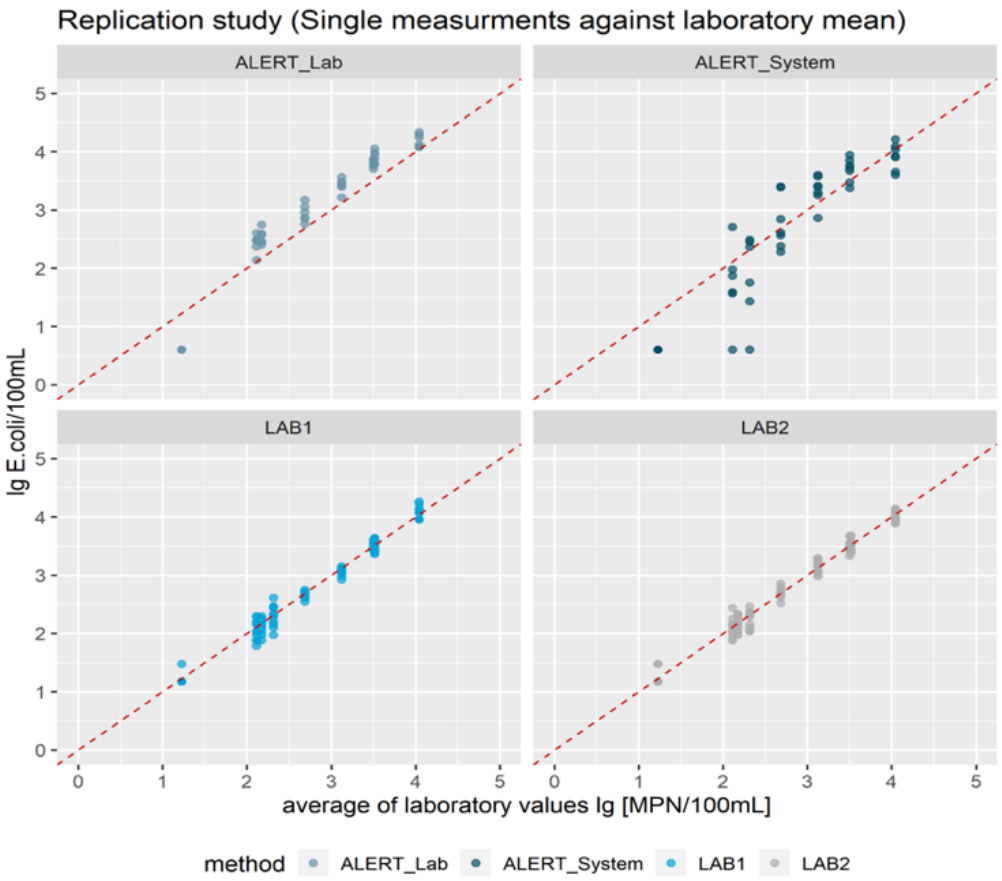

Figure 54 - Repeatability study results. The plots show the individual measurements of the two accredited laboratories (LAB1, LAB2) (N = 12) and the two ALERT devices (ALERT_Lab, ALERT_System) (N=6, N = 7) against the mean of the laboratory values. The red line indicates y = x.

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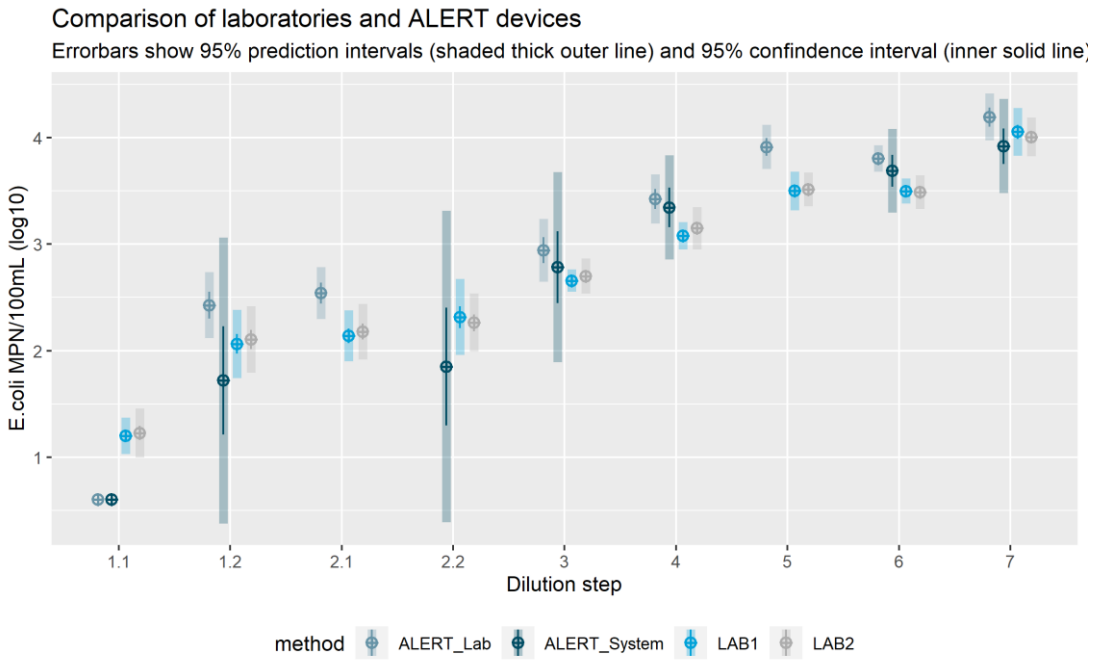

Figure 55 - Repeatability study results. The plots show prediction (outer, thick, shaded interval) and confidence interval (inner, solid) of the two ALERT devices and the two laboratories.

For the ALERT System, it can be observed that at lower concentration a few single very low measurements (outliers) contribute to a lower precision, by comparison with the ALERT LAB and the two laboratories. As all laboratories and both ALERT devices received samples from the same homogenization it appears highly unlikely that these variations are due to homogenization problems of the dilution. The major difference between the ALERT System and ALERT LAB devices is that the V1 version of the ALERT System requires a systematic cleaning and maintenance procedure after seven analyses. This cleaning and maintenance procedure involves a variety of different disinfection (bleach) and rinsing/flushing steps. It seems plausible that variations in the cleaning process and potentials residues of disinfectant in the tubes may lead to the observed outliers, especially at the lower concentration ranges, when the "elimination" of small quantities of bacteria by residues of disinfectant in the tubes already represents a substantial share of the total number of the bacteria included in the sample. This could also explain the improvement of the precision with higher concentrations. It is important to note that the V2 of the ALERT System will contain single-use disposable measurement cartridges, which will completely eliminate the maintenance and cleaning procedure. The V2 of the ALERT System is under active development in DWC and could not be tested during the 2020 season.

3.3.4. Demo-case in Berlin with ALERT V2: Canal water study

In 2021, the experimental setup of 2020 of the repeatability study was replicated between September 17 and September 27 for assessing the bias and precision of the new ALERT System V2 in comparison to laboratory methods, here ISO 9308-3. Except from minor changes the setup and procedures are as in 2020 (see method description). The mentioned minor changes include:

1. Because of the convincing between-laboratory results in 2020, only one laboratory was used.
2. The number of aliquots analyzed by the laboratory was reduced to 8 (instead of 12 in 2020)
3. The base river water was sterilized by autoclaving it instead of filtering over 0.45µm.

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Figure 56 and Figure 57 summarise the main results of the repeatability study conducted in Berlin in 2021. The essential comparison of the repeatability study is the comparison between the ALERT System V1 against the ALERT System V2.

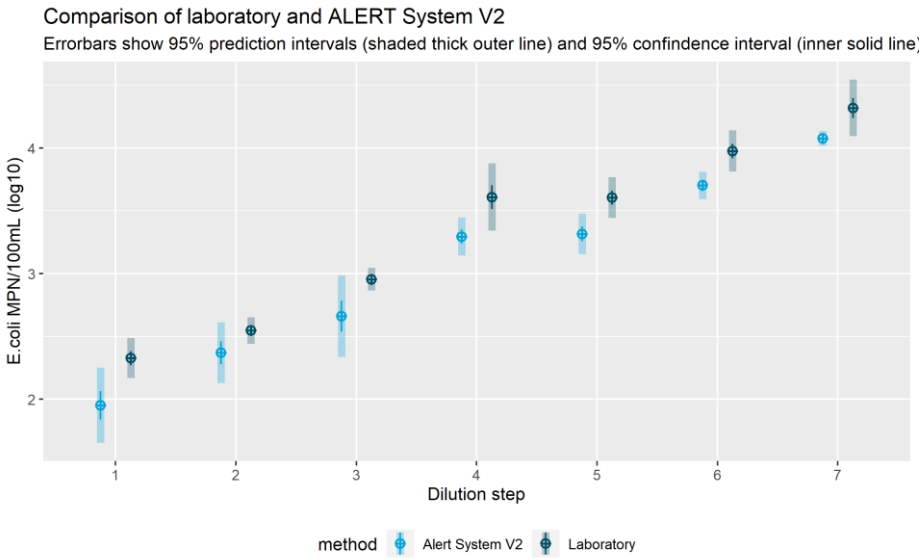

Figure 56: Repeatability study results. The plots show prediction (outer, thick, shaded interval) and confidence interval (inner, solid) of the ALERT System V2 and the laboratory.

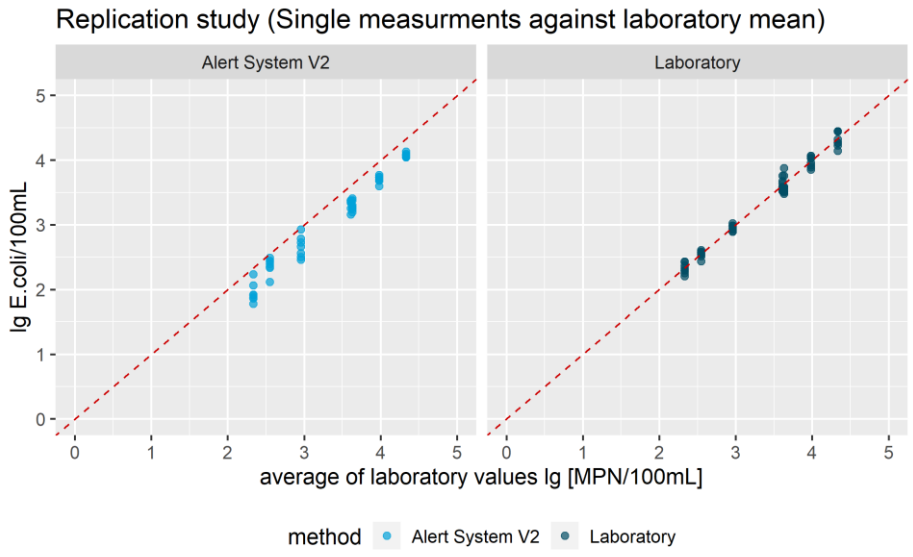

Figure 57: Repeatability study results. The plots show the individual measurements of the accredited laboratory (N = 8) and the ALERT System V2 (N = 7) against the mean of the laboratory values. The red line indicates y = x.

The data show that the precision of the ALERT System V2 at lower concentration was substantially improved, i.e., the measurement uncertainty was significantly reduced in comparison to the ALERT System V1 (Figure 58).

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This observation supports the previous hypothesis that the major cause of the higher variations observed in 2020 was the regular disinfection and maintenance procedures that were required for the ALERT System V1, which introduced many small sources of random error into the operation procedure of the device (see discussion on repeatability study 2020). By replacing this procedure by the use of single-use disposable measurement cartridges on the ALERT System V2, the major sources of error were eliminated and thus the precision improved.

It is interesting to note that at lower concentrations (below 1000), the precision of the ALERT V2 is inferior to that of the laboratory, however at higher concentrations the precision of the ALERT V2 becomes significantly better than the laboratory precision.

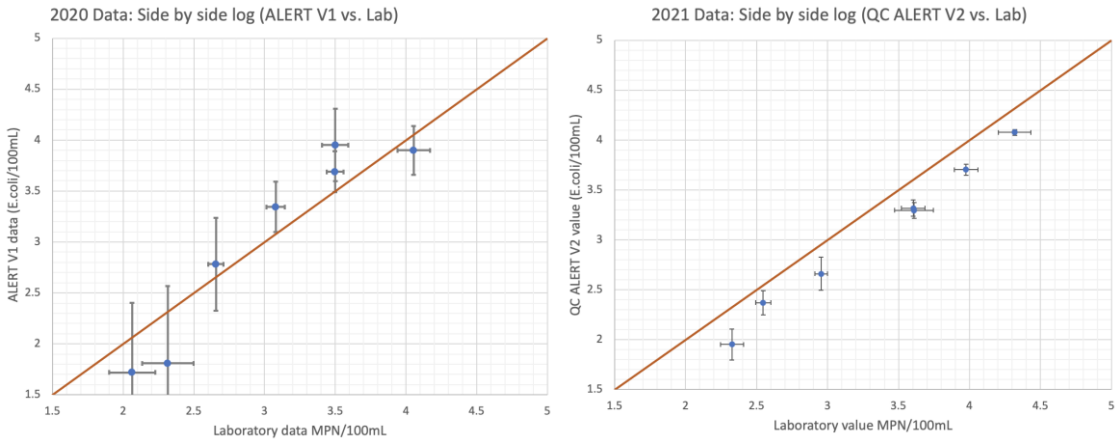

Figure 58: Comparison of the 2020 Alert V1 vs. Lab repeatability data (left figure) and 2021 Alert V2 vs. Lab repeatability data. The improvement in both linearity and precisions for the ALERT V2 is immediately visible. Also visible is the quasi-constant small bias observed in 2021 over the full concentration range. The error bars represent the standard deviation. 95% confidence intervals correspond to 1.96 x standard deviation.

Regarding the bias, it can be observed that in 2021 the ALERT System V2 showed a small (almost uniform) bias over the concentration range, which averaged to -0.27 $\log_{10}$ units. This pattern is similar to the results obtained for the ALERT LAB in 2020, except that in 2020 the ALERT LAB slightly overestimated E. coli in comparison to the laboratory method, whereas in 2021 the ALERT System V2 underestimated E. coli concentration in comparison to the laboratory method. It is important to note that the initial calibration procedures for the ALERT LAB in 2020 and the ALERT System V2 in 2021 are very different, so no comparative conclusions can be drawn directly from this observation.
For an assessment of the practical implication of the observed bias in this experiment, it could be argued that a better understanding of its underlying causes would be desirable. Several potential hypotheses can be mentioned that could account for the difference between the ALERT V2 data and the laboratory data:

1. First, the factory calibration used for calculating the ALERT V2 E. coli values from the measured signal fluorescence times is based on using slightly different protocol, and reference method. In particular, the factory calibration is based on river samples from the Marne river that were filtered using 0.45µm filter to remove existing bacteria, and was then spiked with wastewater influent, itself filtered at 5µm to remove particles. The reference measurement for the factory calibration used the Colilert Quantitray 2000 MPN method, which is an approved method in many countries (ISO 9308-2 2012).

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By comparison, as mentioned above, the 2021 repeatability study in Berlin used autoclaved water and the approved miniaturized 96-well microplate MPN method (ISO 9308-3 1998). So, both the sample preparation and the reference methods were different.

2. Another difference between the factory calibration and the study was that the initial temperature of the sample was room temperature (21 °C), whereas it was variable for the repeatability sample (the autoclaved canal water was at fridge temperature while the effluent used for spiking was not refrigerated). Normally, this is accounted for since the ALERT V2 is outfitted with an external sample temperature probe, which provides the right corrections to account for changes in the sample temperature. However, the temperature correction in the repeatability study may not be fully correct, since the sensor was immersed in refrigerated DI water, not in the canal water + effluent mix, that accounted for the sample and was at a slightly different temperature.
3. Other differences account from the fact that during factory calibration, the reference Quantitray measurement was performed immediately in-house thus assuring identical sample history for the reference and ALERT V2 samples, whereas during the repeatability study the ALERT V2 samples were measured immediately, whereas the laboratory samples were transported in a cooler and only measured several hours later. We have already seen in the 2020 study that transport and cooling can introduce a certain amount of bias. However, in 2020, samples which have been analysed immediately on-site show a positive bias, in 2021 a negative one, which makes this hypothesis for observing a negative bias rather unlikely.
4. The ALERT V2 incubators ensure the control of the incubation sleeve temperature in a closed feedback loop. However, there may be slight offsets between actual sample temperature while incubated, and the incubation sleeve temperature, even after full equilibration. These can come from imperfect thermal contacts between internal control sensor and incubation sleeve, from heat losses through the top and bottom of the cartridge, or from imprecisions of the control temperature sensor (accurate to 0.1 deg. C according to specifications). These can be corrected by using a high-precision certified temperature probe, by introducing individual temperature offsets to each incubator. This correction procedure was not applied to the ALERT V2 under study, which may result in temperatures lower than the setpoint, resulting in slightly longer incubation times than normal until signal detection and lower measurements.
5. Each incubator heating sleeve is outfitted with a temperature cut-off switch as a safety measure. When very cold samples are used, the initial heat injected in the sample can cause the temperature of the sleeve to reach the cut-off temperature, thus disconnecting the heater and limiting the amount of initial heat, which can result in longer time to reach the incubation setpoint, and longer detection times hence lower measurements.
6. Finally, when effluent bacteria are rapidly mixed with the cold water from the refrigerated matrix, they may undergo shock which can lower their metabolism and lengthen the first division cycles. This can result in lower concentration measured by the ALERT, since the signal appears later.

In conclusion, it is very difficult to assess which combination of the above factors can account for the observed differences, and by what respective amount. We do notice that most of the hypotheses described above are somehow related to artifacts of temperature control, or on how sample temperature changes and hold times affect bacterial concentration. The use of an accurate external temperature sensor on the ALERT V2 is therefore essential in order to provide accurate results regardless of the actual temperature of the body of water.

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The important thing to note is that, despite the multiple potential causes for the observed differences, the measurement produced by the ALERT V2 shows exceptional linearity and precision when compared to the laboratory, which means that simple single-point corrections can be reliably applied to correct the observed differences.

The simplest single-point correction that can be applied is an adjustment of offset based on one single data point. To see the effect of such a correction, we will calculate the offset based on the data recorded at the highest concentration (dilution 7), where the ALERT V2 recorded the best precision (standard deviation of 0.03 $\log_{10}$ units). The offset measured at this dilution for the average of ALERT V2 and Lab measurements is A:

A = $\log_{10}$(ALERT V2)-$\log_{10}$(Lab) = -0.2429374 $\log_{10}$ units.

The single-point corrections that will be attempted will consist of subtracting the amount A from the remaining ALERT V2 measurements (offset correction). The results are summarized below, in **Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 59 (please note that the offset correction does not affect the precision, as measured by the standard deviation of the values).

Table 20: Performance of ALERT V2 vs. LAB after single-point offset correction. The second and fourth columns, respectively, assess the precision of the ALERT V2 and LAB, respectively, calculated as the standard deviation of the values.

ALERT V2 (log10) (single-point correction)	ALERT V2 stdev (log10)	Laboratory (log10)	Laboratory stdev (log10)	Residual offset (log10)
2.194	0.153	2.327	0.081	-0.133
2.612	0.123	2.546	0.054	0.066
2.904	0.166	2.955	0.046	-0.051
3.537	0.077	3.610	0.137	-0.072
3.559	0.082	3.604	0.083	-0.045
3.946	0.056	3.975	0.083	-0.030
4.319	0.029	4.319	0.114	0.000

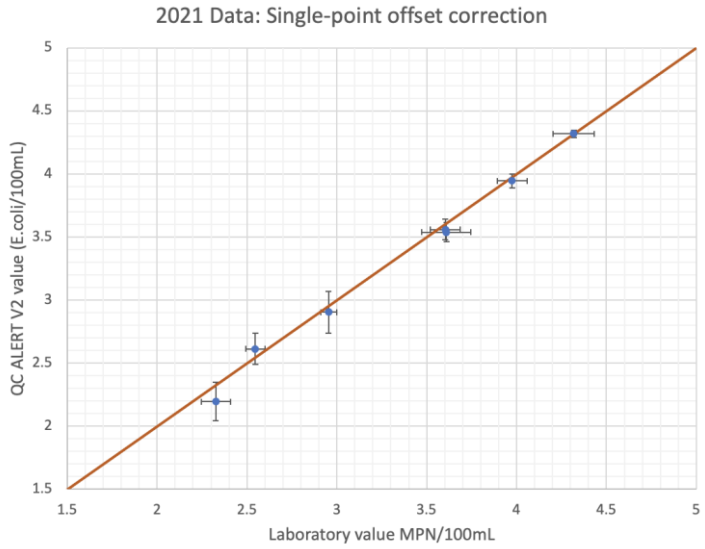

Figure 59: The side-by-side data for ALERT V2 from the 2021 repeatability study, after applying a single-point offset removal by subtracting the offset measured at the highest concentration (where ALERT V2 shows the best precision). The error bars represent the standard deviation. 95% confidence intervals correspond to 1.96 x standard deviation.

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In general, from a health protection perspective a potential underestimation of the existing bacterial concentration might appear to be less protective. However, against the background of the results from the other case studies in DWC and based on the results obtained in Berlin the previous years, this slight underestimation seems rather be an exception, and has not been observed at the other locations so far. Expected differences in the concentration (concentration peaks) of E.coli caused by e.g., discharges from CSO outlets are much higher than the comparatively small observed bias between laboratory and ALERT results. Therefore, the observed bias is not considered to negatively affect the ALERT V2's high potential to reliably detect pollution episodes and thus protect human health at bathing water quality at locations influenced by short-term pollution episodes.

Furthermore, as can be seen in the analysis presented above, this small bias can be simply corrected by performing a single-point adjustment (a procedure that is rapid and easy to perform at any given location), in which case the ALERT V2 data perfectly matches the laboratory over the full concentration range of interest for bathing water monitoring.

3.3.5. Demo-case in Milan with ALERT V1: Water reuse study

Alert data versus lab data were plotted in log scale (Figure 60), in order to evaluate the linear correlation between values and visually identify possible outliers.

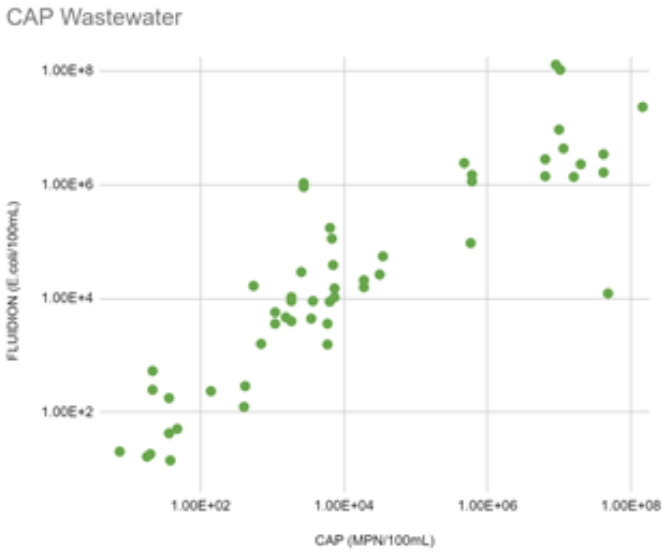

Figure 60: Lab vs Alert data in Milan sampling campaign

The Log10 difference was used to plot the offset between lab and Alert data in a histogram (Figure 61). It can be observed that the distribution is not perfectly symmetric.

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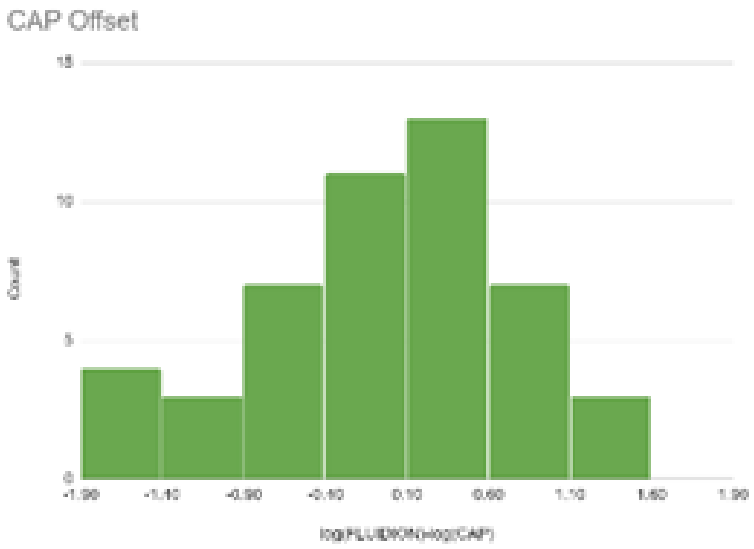

Figure 61: Lab-Alert offset in Milan sampling campaign

The correlation coefficient (R) for data in Figure 41 is 0.8, the bias was calculated to be -0.35 log_{10} units, while the precision (calculated as standard deviation of the log differences) is 1.81 log_{10}units.

Data from the in situ measuring campaign were elaborated to be compared with lab measures. Considering the procedure of the ISO 17994:2014 (ISO 17994:2014, n.d.) to compare microbiological methods, Fluidion data were evaluated against lab measures.

According to the ISO 17994:2014, for the Milan case study, the following parameters were calculated:

$\bar{x}$= -81.72%

s = 417.68%

$\bar{s}$= 50.65%

$W = 101.30\%$

$$x_L = -183.03\%$$

$$x_U = 19.58\%$$

Since $x_L < -2L$ and $x_U > 0$, the result of the comparison is inconclusive and further measures are required.

Considering the US EPA comparison method by calculating the Index of Agreement, it was obtained:

$$IA = 0.88 > 0.7$$

In this case, the comparison between the two set of data can be considered satisfied.

3.3.6. Demo-case in Milan with ALERT V2: Water reuse study

In 2021, two ALERT V2 sampling campaigns were deployed at Peschiera Borromeo WWTP in Milan. During the first 2021 campaign, the ALERT V2 was deployed in floating configuration in a concrete pit, where it measured WWTP effluent, prior to the UV disinfection. The system collected 26 measurements during this first campaign, whereas the laboratory collected 19 side-by-side samples for comparison.

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The two comparative time series are shown in Figure 62 below. As it appears from examining the two-time series, they indicate very similar relative trends, but with an almost constant offset of 0.98 $\log_{10}$ units between the two curves. The laboratory average also seems to be about an order of magnitude too low for untreated effluent, when compared to similar samples measured at other WWTP with similar treatment stages (S. Azimi & V. Rocher, 2021).

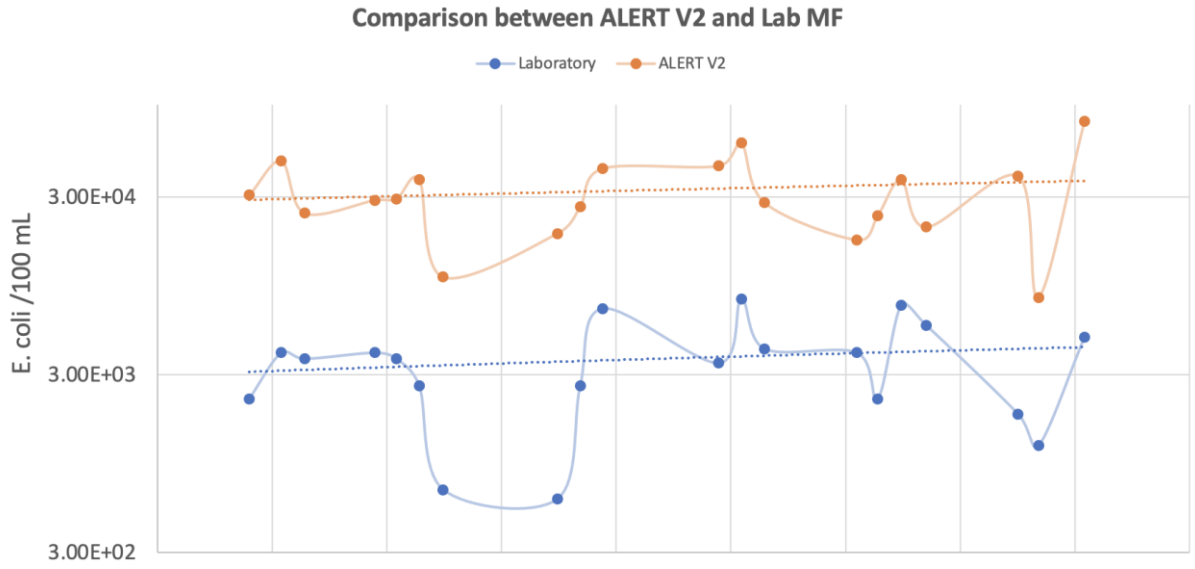

Figure 62: The side-by-side timeseries obtained in the Milan WWTP installation in the first half of the 2021 campaign.

Two hypotheses were considered to understand this offset. The first possibility could stem from the calibration used. The ALERT V2 results were reported according to the Beta2 calibration, which was established internally and was based on river water samples that were spiked with wastewater influent. It is important to note that in previously published studies on ALERT technology [*ibid.*] we have shown that for the wastewater matrix, a slightly different calibration can be derived. Such a pure wastewater matrix calibration has not yet been developed for the ALERT V2. However, two important arguments stand against this hypothesis. First, the previously noted difference between the wastewater and the surface water calibrations is not nearly important enough to account for order-of-magnitude deviations at any concentration. Additionally, the surface water and wastewater calibrations were previously found to cross (i.e., provide identical results) at concentrations of about 30,000 E.coli/100mL, which was the average concentration measured at the wastewater plant in Milan. Therefore, this hypothesis was discarded as being the main source of the observed offset.

The second hypothesis is that in the WWTP effluent at the installation site there was a significant presence of important amounts of bacteria attached to particles. It is known from other measurements (TSS) that a large quantity of solids is present in the effluent. Faecal particles can create large discrepancies between the standard laboratory method and the ALERT V2 method, which originates from the fact that the standard methods (either membrane filtration and plating, as used here, or the most probable number MPN method) are unable to quantify attached bacteria. Indeed, a faecal particle is counted as a single bacterium by the standard laboratory methods, although it could contain thousands of bacteria in reality. By contrast, ALERT V2 does measure all the bacteria present in the sample, including all the bacteria attached to particles, since they all contribute to the substrate metabolization which generates the fluorescent signal. This difference is fundamental and leads to a number of interesting questions that will be outlined later.

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In order to test this second hypothesis, a second campaign was initiated in 2021. This time, alternate V2 cartridges were installed with, and without filters: 1,3,5 did not have filters (i.e., were identical to the ones used in the first campaign), whereas 2,4 and 6 had 5µm sterile glass fiber syringe filters installed. Cartridge 7 was not used. At every sampling time, two samples were analysed in the ALERT V2, one which was not filtered (similar to first campaign), and one which was automatically filtered at 5µm at sampling time. Please note that the 5µm filtration size is larger than a bacterium (0.5µm diameter, 2µm length) so this filter will remove large particles but may still allow smaller bacterial aggregates to pass through.

A total of 11 laboratory samplings were performed, with results from the laboratory, ALERT V2 without filter, and ALERT V2 filtered. Figure 63 below shows the comparative time series. It is indeed observed that every filtered ALERT V2 measurement shows significantly lower bacterial charge than its unfiltered counterpart, sometimes by as much as 1.83 $\log_{10}$ units (0.62 $\log_{10}$ units on average), which positively proves that particles play a major role in the observed phenomenon, and that the large majority of bacteria is attached to particles larger than 5µm. These are real effects and cannot be attributed to random error, since the precision of the ALERT V2 has been proven to be between 0.03 and 0.07 $\log_{10}$ units for this range of concentrations (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

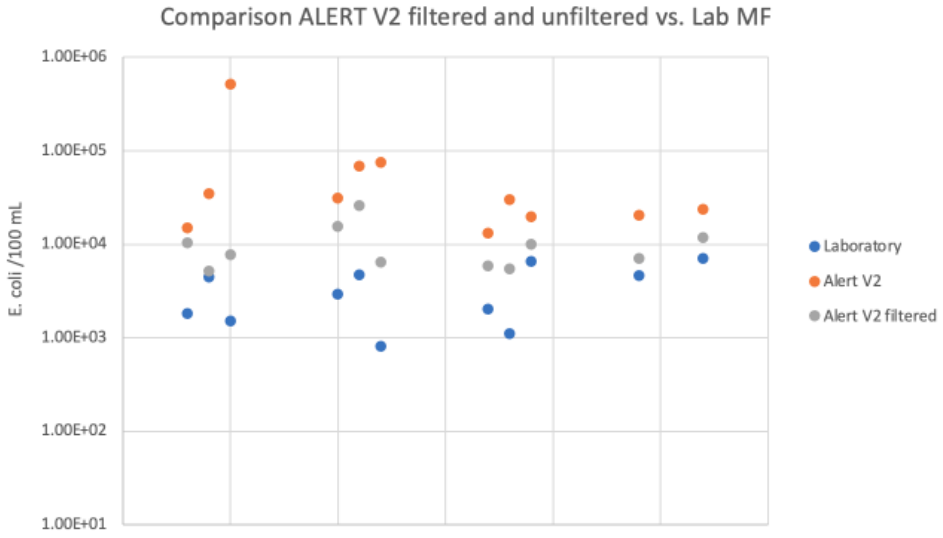

Figure 63:Comparative time series obtained during the second 2021 ALERT V2 campaign at the Peschiera Borromeo WWTP. The laboratory data (in blue) is compared to the ALERT V2 unfiltered sample (orange) and, respectively, with the ALERT V2 sample filtered at 5µm (in light gray)

It is also observed in Figure 63 and also in Figure 64 below that the ALERT V2 filtered measurement values are significantly closer to the laboratory value (e.g. to the identity line) but still slightly higher, which suggests that particles smaller than 5µm which may pass through the filter are also present. For some of the data points the ALERT V2 and laboratory measurements are very close, within 0.20 $\log_{10}$ units. It would be interesting to see if the TSS measurements at those times recorded lower amounts of suspended solid matter.

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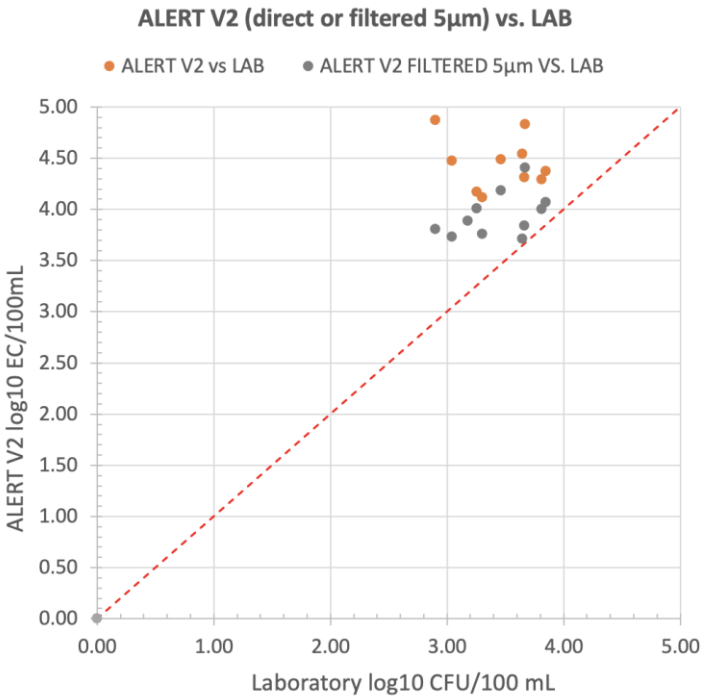

Figure 64:Side-by-side plot of the laboratory data, ALERT V2 data and ALERT V2 filtered data for the datapoints collected in the second 2021 campaign. The dotted red line indicates the identity line.

These observations require a discussion, since they raise interesting questions about the ability of the standard laboratory methods to assess the full bacterial charge in situations where particles may be present in the effluent, and about how that difference can affect the risk assessment.

The ALERT V2 measurement can assess the full bacterial charge present in the sample. As demonstrated above, appropriate filtration can be integrated to the ALERT V2 cartridge so as to eliminate particles and focus on free-floating bacteria, thus providing very complete information about the total bacterial charge and its partition between free and attached bacteria.

It is important to note that the ALERT V2 installation site was not ideally located during this study to assess risk associated with water reuse for irrigation, for the simple fact that, due to practical reasons, it was installed upstream of the UV disinfection unit, which is a key part of the treatment. It would be interesting, in the future, to plan for three installation sites: prior to UV disinfection (like in the 2021 campaign), but also post-disinfection and post-discharge into the irrigation canals. Ideally, both filtered and unfiltered samples would be collected with ALERT V2, to assess both free-floating and attached bacterial fractions at all these sites, and thus provide information about real-time abatement factors obtained through the UV process, but also about the final health risks associated with the delivered reuse water.

3.3.7. Benchmarking and comparison of ALERT data in the three case studies

To obtain a benchmarking of ALERT devices performance between the three case studies, in Table 21 are compared different indicators, which include correlation coefficient, bias, precision and IA. All these indexes were used in this study to evaluate the agreement between microbiological data obtained by ALERT.

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It is important to note that in 2019 Paris and Milan cases, the results were aggregated over many different types of samples, sometimes using different protocols. The benchmarking factors therefore are not uniform, do not reflect the expected performance in a fixed environment or water matrix, and should be used with caution.

In the Berlin case, there were two studies that used different methodologies. Both are reported. The 2019 study used an ALERT System in the Spree river, compared to side-by-side lab measurements. In 2019 no assessment was done of inter laboratory variability, or of repeatability. ALERT LAB was not used in 2019.

In 2020, the BERLIN study used a different methodology. Both ALERT System V1 and ALERT LAB were assessed, and two laboratory measurements were systematically performed for each determination, to allow an evaluation of the current capabilities using the regulatory approved methods (i.e., benchmarking of the approved laboratory 1 data against approved laboratory 2 data).

It is also important to note that the ALERT SYSTEM used in all the pre-2020 studies was the V1, which requires manual disinfection of the tubes between two measurements. It was apparent that the poorer precision of the ALERT V1 (visible only at lower concentrations) was due to residual disinfectant leftover from the maintenance killing a portion of the bacterial load.

The ALERT SYSTEM V2 eliminates the previous issues noted with the ALERT V1 by introducing a novel disposable cartridge concept that does not require manual maintenance or disinfection procedures. The results from V2 testing are shown in light green background in Table 21 for the operational tests performed in-situ (PARIS, MILAN), and in darker gray background for the laboratory benchmarking (repeatability study, BERLIN). Pre-2021 data is shown in orange background, and only pertains to operational data collected in-situ.

In 2021, only the repeatability study in Berlin provides a quantitative basis for comparing the performance of ALERT SYSTEM V2 *vs.* the previous version of the product, ALERT SYSTEM V1. The major improvements in metrology performance measured for the ALERT V2, both in terms of linearity and precision, demonstrate that the single-use cartridge concept does eliminate the errors associated with residual disinfectant left in the sampling tubes after the maintenance procedures, which affected the measurements of the ALERT V1, particularly at the low end of the concentration range. The excellent linearity allows correcting the observed offset which was constant over the full concentration range using a single-point correction. It is recommended that this correction be applied at a concentration around 1.0E+4 E.coli/100 mL, where the ALERT V2 shows the highest level of precision. With such simple single-point correction, the ALERT V2 data becomes of similar quality to the laboratory data, both in terms of accuracy and precision (the laboratory shows slightly better precision at concentrations below 1.0E+3, whereas ALERT V2 is more precise than the laboratory at higher concentrations). The offset correction procedure, as well as a discussion regarding the possible causes for offset appearance, are provided in Section 3.3.4.

The 2021 campaigns in Paris and Milan demonstrated the successful operational deployment in both outdoor riverine settings, and within a wastewater treatment plant. The Paris 2021 side-by-side data, although insufficient for applying ISO or EPA methodology for method comparison, demonstrates the excellent agreement of ALERT V2 and laboratory data, both in terms of bias (0.058 $\log_{10}$ units) and precision (0.099 $\log_{10}$ units, and coherent with the one measured in the repeatability study).

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The data from the Milan 2021 campaign identifies the reason for the large bias observed at this location, which consists of the presence of large bacterial charges on particles that cannot be measured using either MPN or membrane filtration standard laboratory methods but is measured with the ALERT V2. It was also shown that the ALERT V2 can be installed with a prefilter to eliminate the large particles, in which case the results are considerably closer to those measured by the laboratory. Neither ISO nor EPA methodology can be applied on these data for the above reason. The same is true of the 2019 data, with the difference that the 2021 campaign allowed positively identifying the reasons for the disagreement and showing that the observed bias is not related to the ALERT V2 instrument but rather to the composition of the particular matrix and to the limitations of the standard methods.

Table 21: Summary of parameters that can be used as benchmarking of ALERT system in the three demo-cases (please read disclaimers above)

	CORRELATION COEFFICIENT (R)	**BIAS**	**PRECISION**	**ISO 17994:2014**	**IA (US-EPA method)**
PARIS 2019 ALERT V1, LAB	0.9	-0.029 $\log_{10}$ units	0.34 $\log_{10}$ units	Inconclusive	0.96 > 0.7
PARIS 2021 ALERT V2	N/A	0.06 $\log_{10}$ units	0.10 $\log_{10}$ units	N/A	N/A
BERLIN 2021 ALERT V2	0.99	-0.24 $\log_{10}$ removable with single point offset correction	From 0.03 $\log_{10}$ (@1E4 MPN/100mL) to 0.15 $\log_{10}$ (@1E2 MPN/100mL)	N/A	N/A
BERLIN 2020 ALERT LAB SPREE	N/A	0.12 $\log_{10}$ units	0.28 $\log_{10}$ units	N/A	N/A
BERLIN 2020 ALERT V1 SPREE	N/A	0.03 $\log_{10}$ units	0.47 $\log_{10}$ units	N/A	N/A
BERLIN 2020 LAB SPREE	N/A	0.02 $\log_{10}$ units	0.20 $\log_{10}$ units	N/A	N/A
BERLIN 2019 ALERT V1 SPREE	0.8	-0.10 $\log_{10}$ units	0.58 $\log_{10}$ units	Inconclusive	0.90 > 0.7
MILAN 2021 ALERT V2	N/A	In the Milan 2021 study the difference between the ALERT V2 and the laboratory is probably due to a major portion of the bacterial load not being detected by the laboratory, due to the presence of significant amounts of bacteria attached to particles.			
MILAN 2019 ALERT V1 ALERT LAB	0.8	-0.355 $\log_{10}$ units	1.81 $\log_{10}$ units	Inconclusive	0.88 > 0.7

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Overall, the different campaigns performed in 2019, 2020 and 2021 capture the limitations of the previous version of the ALERT System technology, and demonstrate the major improvements obtained in the ALERT V2 through the use of disposable cartridges. Through the different series of operational deployments and in-lab repeatability studies performed independently within DWC, between 2019 and 2021, by industry professionals, and analysed using approved laboratories, ALERT V2 and the ALERT LAB were validated as accurate and precise bacterial measurement systems that enable both in-situ and, respectively, portable analyses of samples to be performed with outstanding simplicity, very limited human intervention, and without having to send samples to an external approved laboratory. The best practices in terms of offset correction at new deployment sites, to obtain maximum accuracy from the instrument, are described as well.

3.4. Data analysis of on-line sensors for water quality monitoring

Data analysis of on-line sensors for water quality monitoring was particularly important in the Milan case-study, where in situ measurements can be used for the real-time monitoring of wastewater quality and to continuously ascertain its compliance with reuse regulation. In this study, bias analysis of probe reading, and detection of outliers were performed for the on-line measurements of TSS, NH_4, NNO_3, and PPO_4 in the final effluent.

3.4.1. Bias analysis

As discussed in Section 2.3, maintenance of probes is paramount to obtain reliable signals, which need to be periodically compared with data obtained by laboratory analyses to confirm the goodness of the probe reading. According to the scientific literature, acceptable probe errors are < 20% (Cecconi et al., 2019). For the Milan case-study, prob and lab data sets were available for TSS, NH_4, NNO_3, and PPO_4 measurements in the final wastewater effluent. Table 22 and Table 23 summarize the information of collected data points for various parameters in Lab and by probs, respectively.

Table 22: Statistical information of the collected data points in Lab and by probs for various parameters of interest

The properties of measured data in Lab					
Parameter	**Data points**	**First measurement (month/day/year)**	**Last measurement (month/day/year)**	**Min of data**	**Max of data**
NH_4	185	08/01/2018	23/06/2021	0.5	15.5
TSS	185	08/01/2018	23/06/2021	5.0	38.0
NNO_3	127	08/01/2018	22/06/2020	2.1	13.0
PPO_4	126	08/01/2018	22/06/2021	0.2	1.3

The properties of measured data by Prob					
Parameter	**Data points**	**First measurement (month/day/year)**	**Last measurement (month/day/year)**	**Min of data**	**Max of data**
NH_4	78696	04/01/2018	25/06/2021	0.0	75
TSS	65367	12/11/2018	25/06/2021	0.0	37805
NNO_3	112206	04/01/2018	25/06/2021	0.0	47
PPO_4	54991	04/01/2018	25/06/2021	0.0	11.5

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Since the Lab data points are daily averaged, to have a clear comparison between the lab and prob datasets we used the prob measurements in daily-average form. It should be noted that when the measured values in Lab or by probs are less than the lab detection limit, it was considered the detection limit itself.

Table 23 summarizes the daily-averaged information of the measured data points for the parameters of interest.

Table 23: Statistical information of the daily-averaged prob measurements for various parameters of interest

The properties of measured DAILY AVERAGED data by Prob					
Parameter	**Data points**	**First measurement (month/day/year)**	**Last measurement (month/day/year)**	**Min of data**	**Max of data**
NH_4	948	04/01/2018	25/06/2021	0.5	25
TSS	797	12/11/2018	25/06/2021	1.3	9321
NNO_3	1050	04/01/2018	25/06/2021	0.0	18
PPO_4	1008	04/01/2018	25/06/2021	0.0	9

Results of the bias analysis showed that the investigated probes at Peschiera-Borromeo WWTP did not produce reliable data, except the Nitratax sc sensor for a limited period. Details of the bias analysis performed for TSS, N-NH_4, N-NO_3, and PPO_4 is reported below.

Nitrates

Figure 65 illustrates the variation trend of N-NO_3 for Lab and prob measurements from January 2018 till July 2021. For clear inspection, the lab data points are intrinsically daily averaged, but the prob data points are averaged over 24 hours period. The lab data points range between 2.1 to 13 mg/l; however, the prob data points for N-NO_3 are in the range of 0.6 to 17.9 mg/l. Hence, there is a good overlap for some lab and prob measurements. However, there is room to debate on the period when the prob functionality was satisfying. To recognize this period, we will exploit the error analysis.

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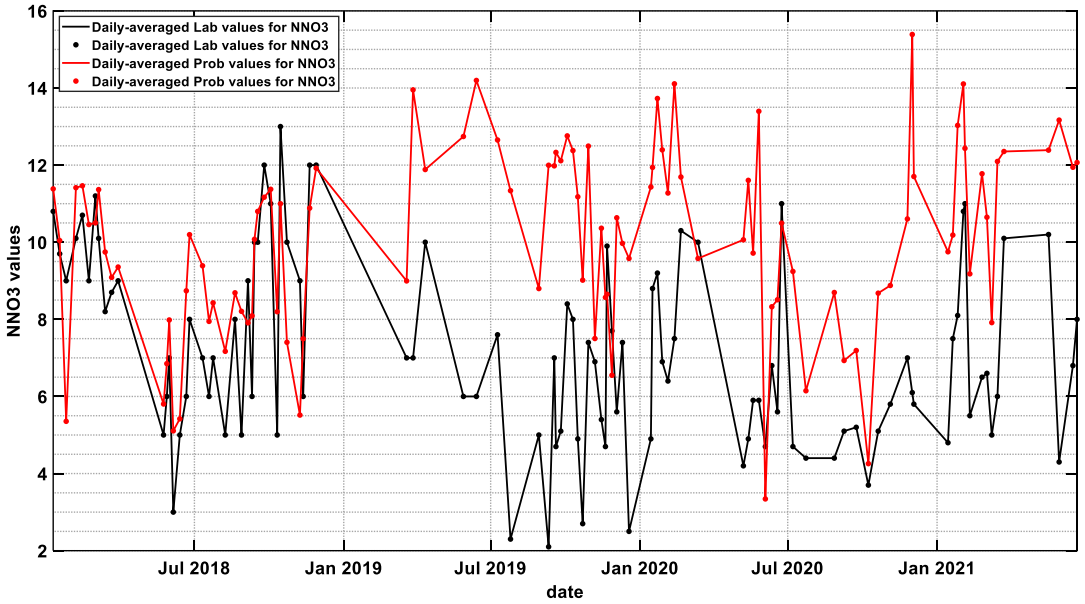

Figure 65. Variation trend of NO_3 against time (day) for Lab and daily averaged prob data points

Figure 66 illustrates the scatter diagram between the measured (at the lab) and predicted (by the probs) TSS, as well as the error bands associated with the error, ranges $\pm 25, \pm 50, and \pm 75\%$. The black solid line represents the fit line on which all the predicted and measured values are the same. Inspection of

Figure 66 reveals that (1) the prob measurements are generally overestimated since most data points are above the fit line, (2) there are data points whose error is less than 25%.

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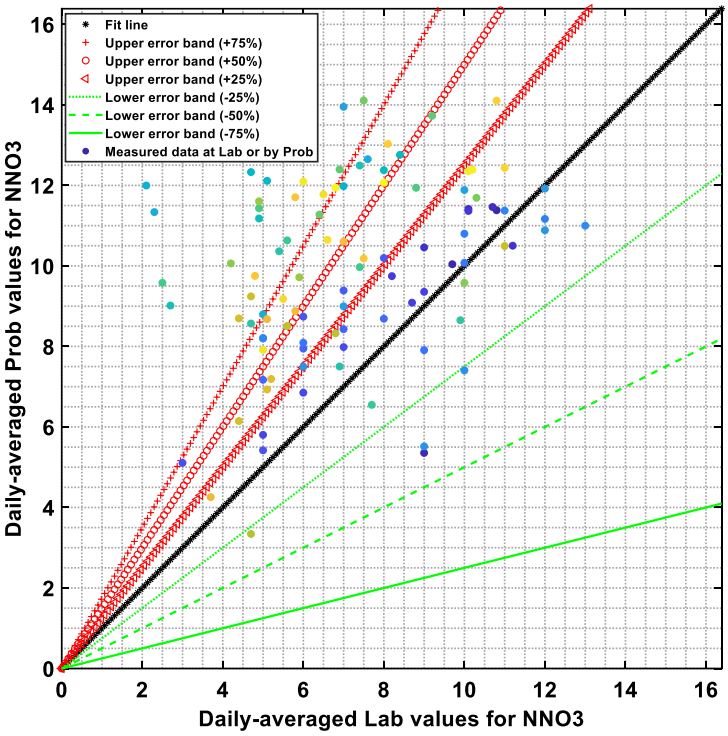

Figure 66. Scatter plot between the measured and predicted NO_3

Figure 67 shows the time series of calculated probe error at various days. The threshold line corresponds to the absolute error equals 0.2 (or 20%). The days, whose prob measurements are larger than the predefined threshold, are beyond our satisfactory results. Inspection of the figure reveals the following results:

1. The maximum errors are 471.27, 392.91, 283.16 % associated with 10-Sep-2019, 25-Jul-2019, and 18-Dec-2019, respectively.
2. After 19-Mar-2019 the prob failed to correctly capture the NO_3 values. However, before this date, some of the measurements are in line with the lab values. We will use the data points of this period (known as Selected prob data) to evaluate the robustness and accuracy of the approaches we developed for the outlier detection (see Section 3.2). In this period, there are 38 data points in which only 15 data points have an absolute error larger than 20%.

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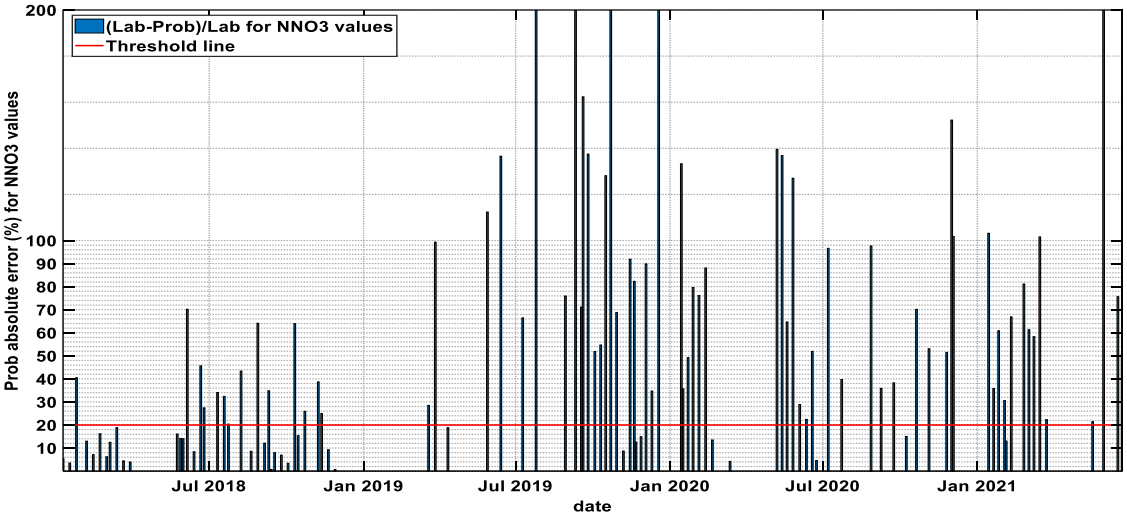

Figure 67. Prob absolute error against date for NO_3 for all the measured period

Ammonia

Figure 68 illustrates the variation trend of NH_4 for Lab and prob measurements from January 2018 till June 2021. As shown, the daily-averaged prob data points are plotted against lab data points (which are intrinsically daily averaged).

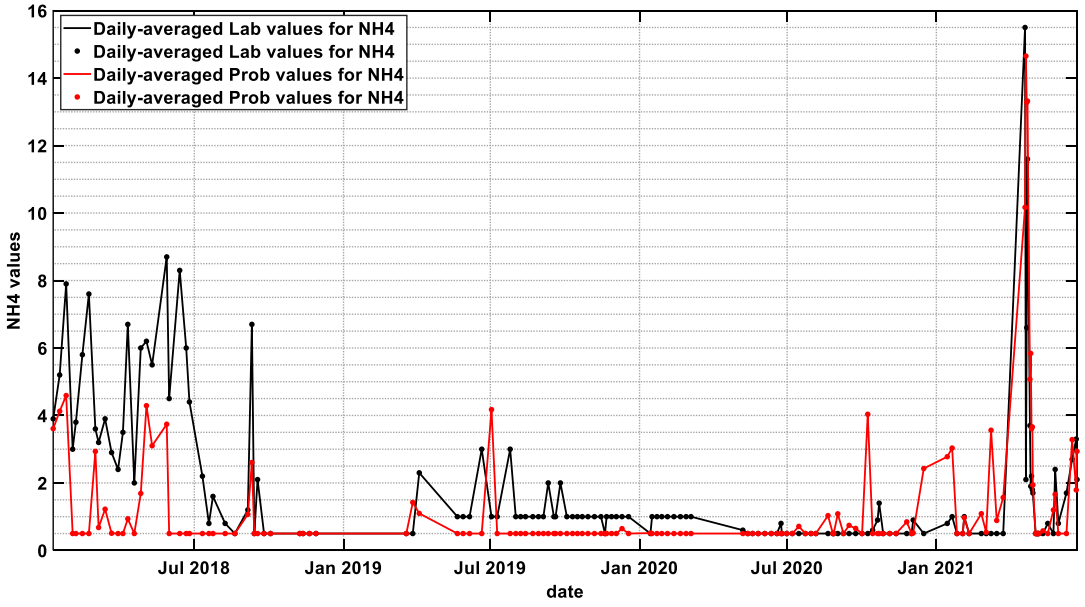

Figure 68. Variation trend of NH4 against time (day) for Lab and daily averaged prob data points

Figure 69 illustrates the scatter diagram between the measured (at the lab) and predicted (by the probs) NH_4, as well as the error bands associated with the error, ranges $\pm 25, \pm 50, and \pm 75\%$. The black solid line represents the fit line on which all the predicted and measured values are the same. As indicated, the majority of data points are beyond the lower error band with -75% error. This is indicative of sensors malfunction.

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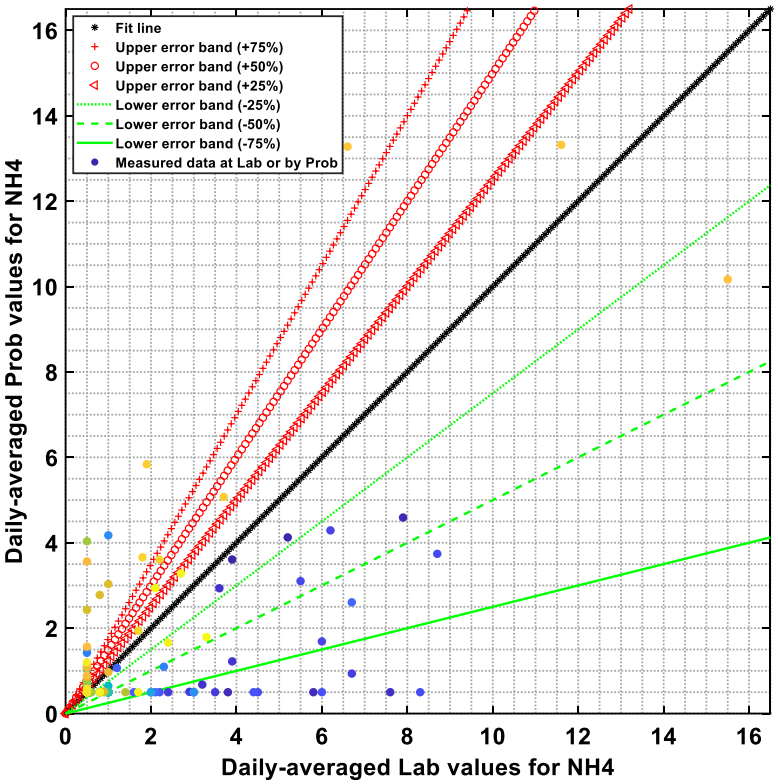

Figure 69. Scatter plot between the measured and predicted NH4

Hence, these results prove that the utilized sensor fails to well capture the NH_4 concentration in wastewater. Accordingly, the registered data for NH_4 is valid only in 12 days out of 148 days (when we have both the lab and prob measurements). In other words, only **7.5%** of prob measurements are acceptable (their bias is less than 20%) based on the predefined Bias calculated by Eq (3.24).

Total Suspended Solids

Figure 70 illustrates the variation trend of TSS for Lab and prob measurements from November 2018 till July 2021. The lab data points range between 5 to 38 mg/l; however, the prob data points for TSS are in the range of 1.33 to 60846 mg/l. Accordingly, it is expected to have the majority of prob data points as outliers.

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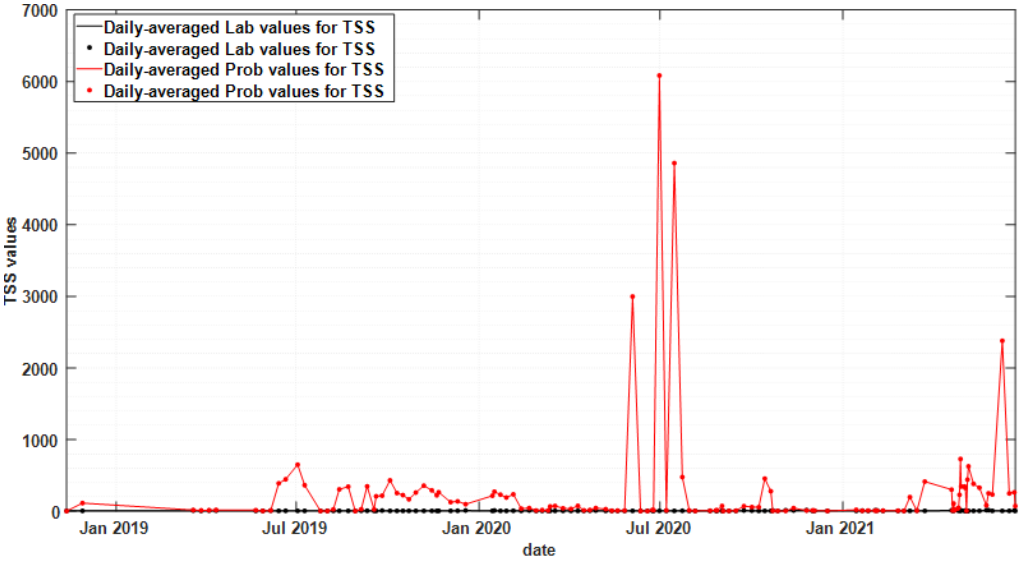

Figure 70. Variation trend of TSS against time (day) for Lab and daily averaged prob data points

Figure 71 illustrates the scatter diagram between the measured (at the lab) and predicted (by the probs) TSS, as well as the error bands associated with the error, ranges $\pm 25, \pm 50, and \pm 75\%$. The black solid line represents the fit line on which all the predicted and measured values are the same. As shown, almost all the data points exceed the predefined error bands which indicate the predicted data points inaccuracy. The data points are located over the error band $+75\%$ which means that the prob data are significantly overestimated.

Figure 71. Scatter plot between the measured and predicted TSS

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Phosphates

Figure 72 illustrates the time series of PPO_4 for Lab and prob measurements from January 2018 till July 2020. Both lab and prob data points are daily averaged and the values less than 0.5 are considered to be 0.5. The lab data points for P-PO_4 are in the range of 0.2 to 1.3. However, the prob records range between 0.0 and 3.05. That is why in many days the prob overpredicts the lab measurements.

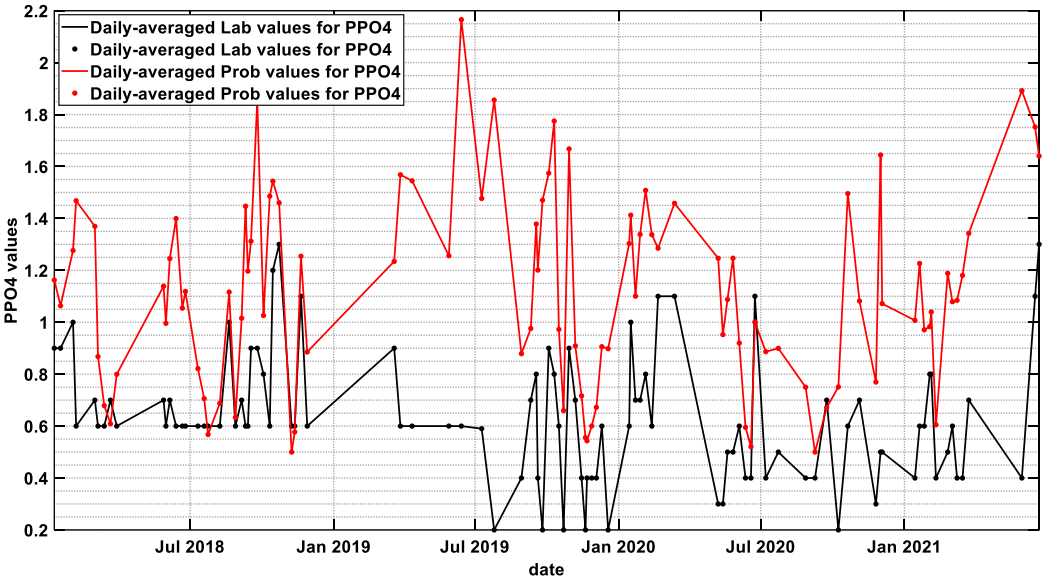

Figure 72. Variation trend of PPO_4 against time (day) for Lab and daily averaged prob data points

Figure 73 illustrates the scatter diagram between the measured (at the lab) and predicted (by the probs) PPO_4, as well as the error bands associated with error ranges $\pm 25, \pm 50, and \ \pm 75\%$. The black solid line represents the fit line on which all the predicted and measured values are the same. Inspection of Figure 73 reveals that (1) the prob measurements are generally overestimated since the majority of data points are above the fit line, (2) it is interesting that there are many days whose measured values for the PPO_4 is constant (around 0.6 mg/l), but the prob records various values ranging from 0.5 to 2.2mg/l in these days, (3) the error associated mostly exceeds +25% although the data points are concentrated in the range of 0.5-1.3 mg/l. Reassuming, most of P-PO_4 probe measurements were affected by not acceptable errors.

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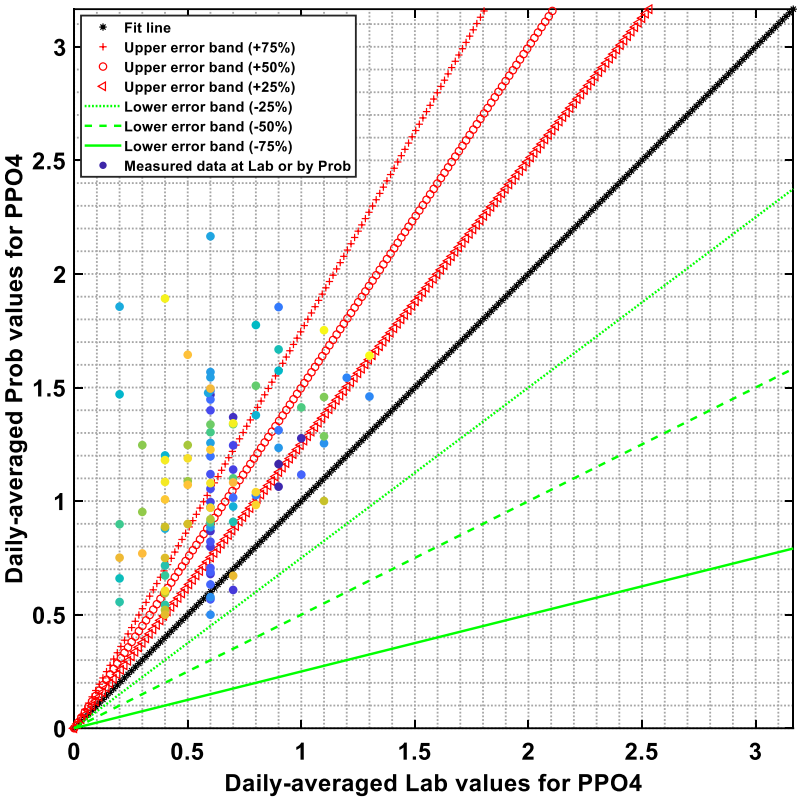

Figure 73. Scatter plot between the measured and predicted PPO_4

3.4.2. Performance of the outlier detection methods

The bias analysis in Section 3.4.1 proved that the performance of all the sensors, except N-NO_3 for a limited period, was not accurate. Hence, in the following section, the performance of various outlier detection methods was investigated using the NNO3 prob measurements in the selected period (i.e., January 2018 until March 2019). Nevertheless, for completeness of the study, analysis on the full dataset were anyway elaborated for nitrates. Even if the dataset contained a very huge number of sensors faults, the outlier detection method based on the integration of M-SAD and T-squared methods was still able to improve data quality. The analyses for the full period are reported in Annex C.

Nitrates – Selected prob data (January 2018: March 2019)

As discussed in the previous Section 3.4.1, the prob measurements are more accurate between January 2018 and March 2019. Hence, in this section, the prob data recorded during these dates are examined. There are totally 38 daily-averaged lab and prob measurements among which the error (see Eq. (3.24)) of 15 daily-averaged prob measurements (around 39.41%) exceed 20%. Moreover, mean prob errors before cleaning is 21%.

Below are discussed the performance of the different outliers detection methods investigated in this study.

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M-SAD performance

As shown in Figure 74, the best performance of the M-SAD outlier detection method is achieved when window size is 325. As indicated, implementing M-SAD method with window length equals to 325 improved the prob measurements accuracy by 10.08% and reduced 40.71% of the datapoints whose error were more than 20% (Figure 75-Figure 76).

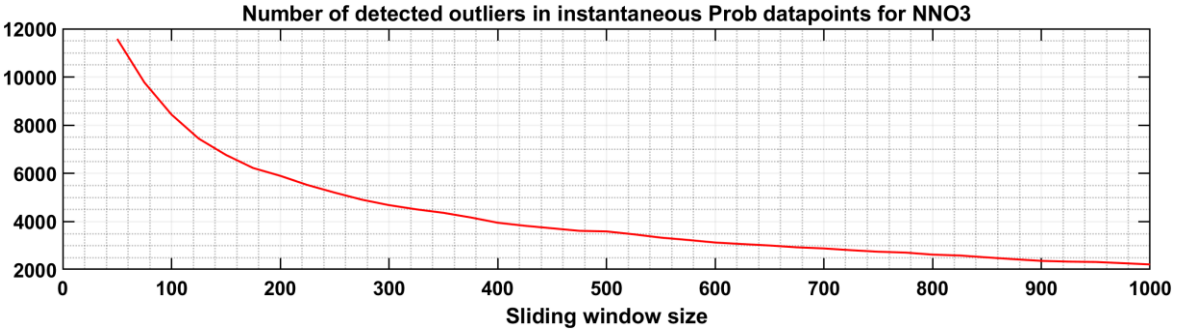

Figure 74. Number of detected outliers V.S. window length in instantaneous Prob datapoints for NNO3

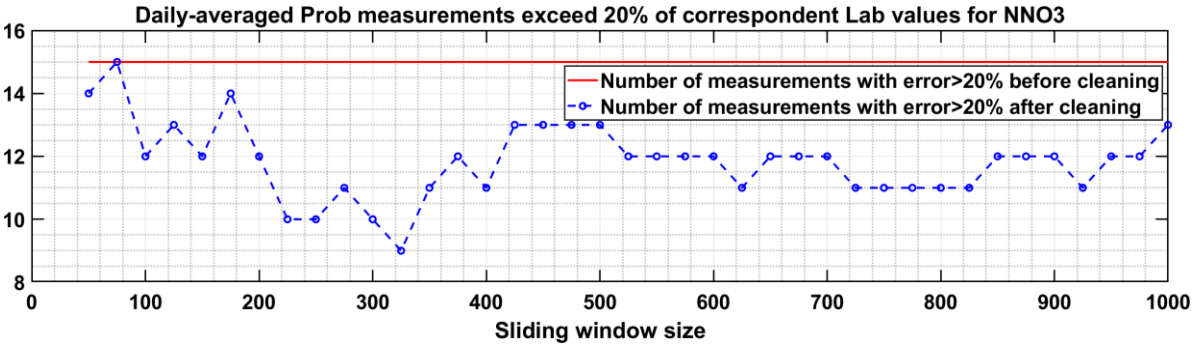

Figure 75. Daily-averaged prob measurements exceed 20% of correspondent Lab values for NNO3

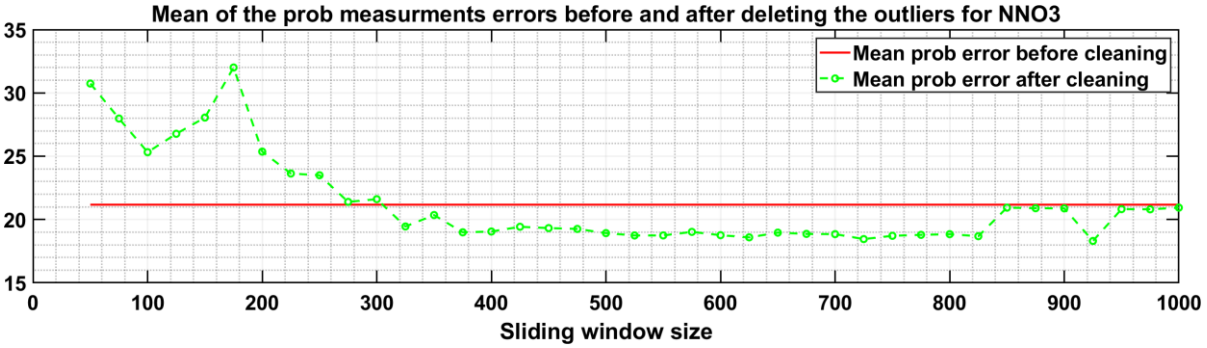

Figure 76. Mean of the errors of prob measurements before and after deleting the outliers for NNO3

Considering window size = 325, the detected outliers out of prob instantaneous measurements are plotted in Figure 77.

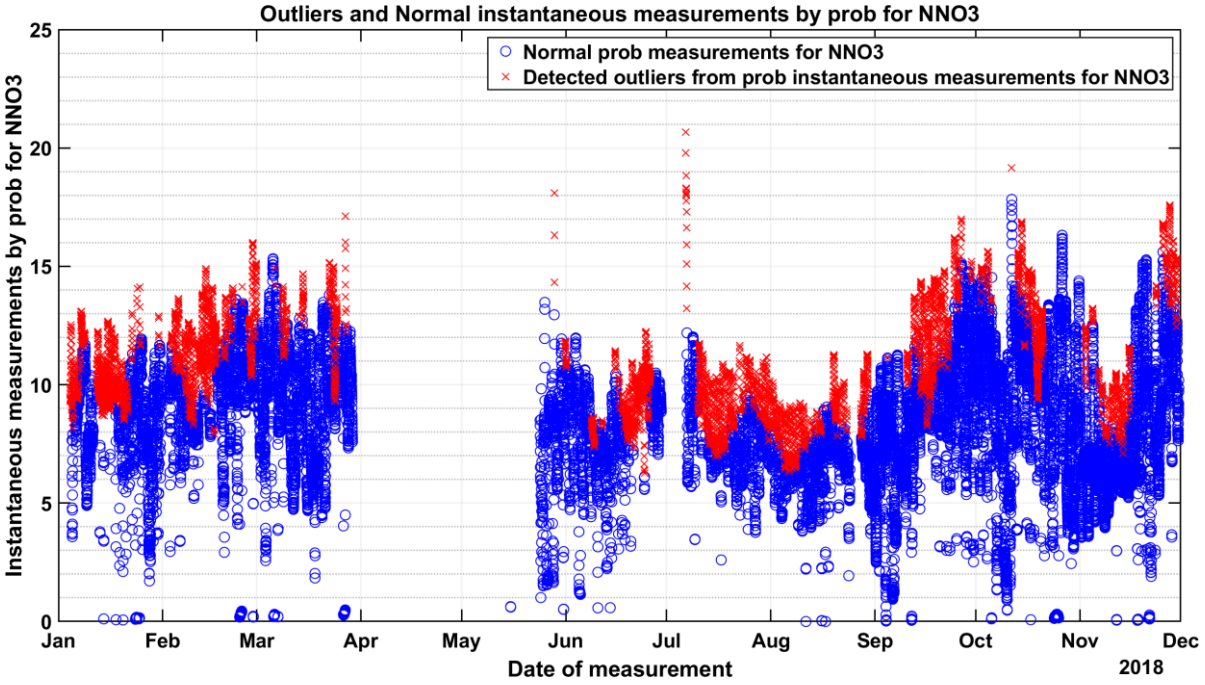

Figure 77: Outliers and Normal instantaneous measurements by prob for NNO3 in 2018

M-AAD performance

M-AAD fails to well capture the outliers. Their performance in detecting of outliers are shown in Figure 78. However, the model performance is a bit better when the window size assumes selected values, including 325 (Figure 79 - Figure 80).

Figure 78. Number of detected outliers V.S. window length in instantaneous Prob datapoints for NNO3

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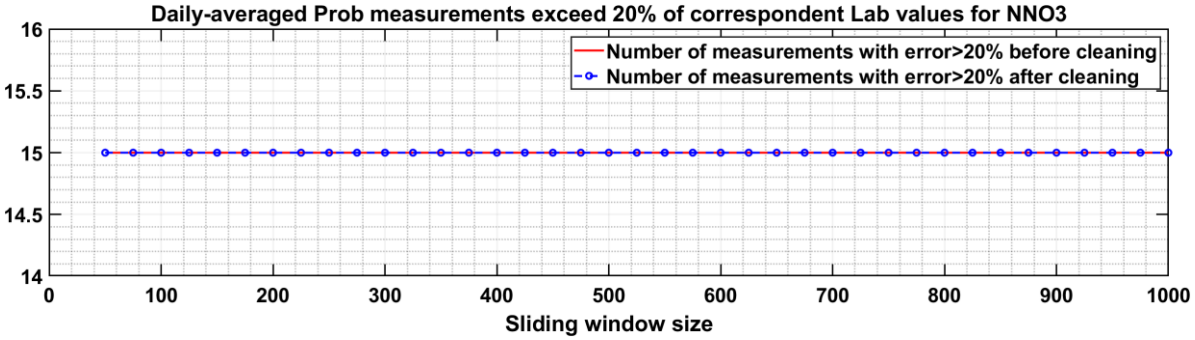

Figure 79. Daily-averaged prob measurements exceed 20% of correspondent Lab values for NNO3

Figure 80. Mean of the errors of prob measurements before and after deleting the outliers for NNO3

Considering window size = 325, the detected outliers out of prob instantaneous measurements are plotted in Figure 81.

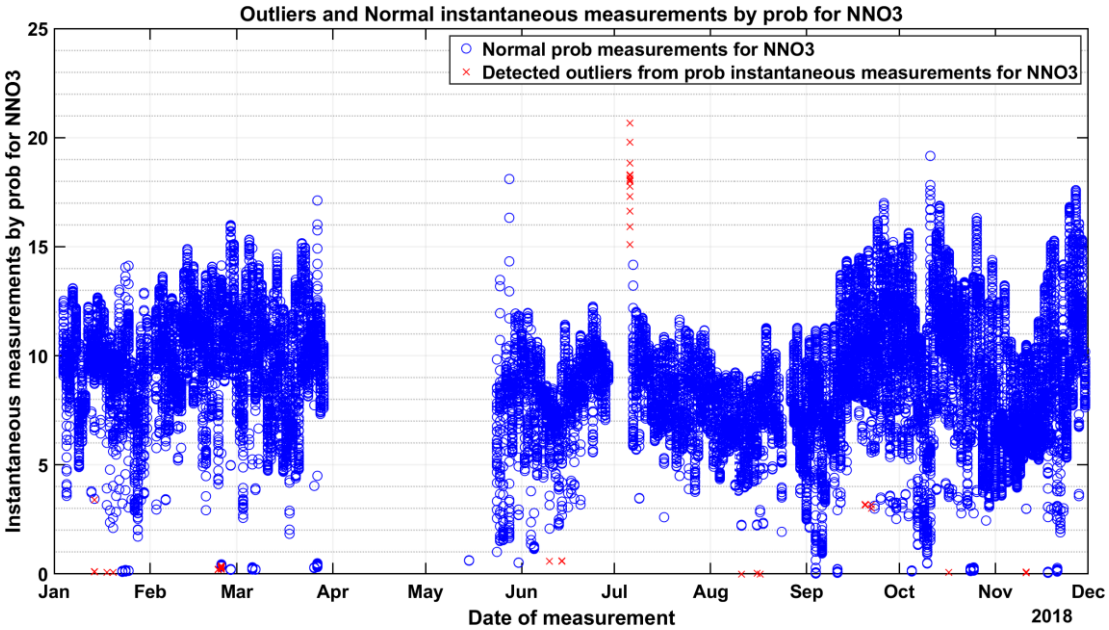

Figure 81: Outliers and Normal instantaneous measurements by prob for selected NNO3 data in 2018; application of M-AAD method

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M-MAD performance

M-AAD fails to well capture the outliers. The performance in detecting outliers is shown in Figure 82-Figure 84. However, even in this case, the model performance is a bit better when the window size is 325. Particularly, in this case, it is the lowest the number of measurements with error >20% after cleaning.

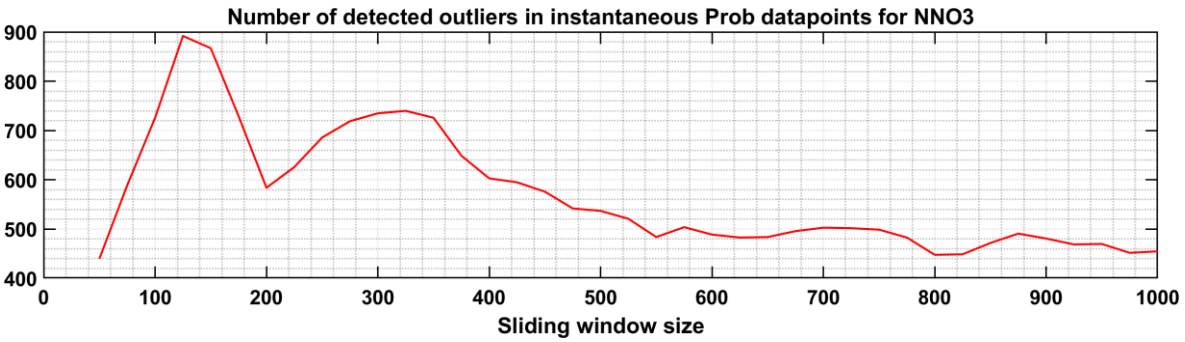

Figure 82. Number of detected outliers V.S. window length in instantaneous Prob datapoints for NNO3

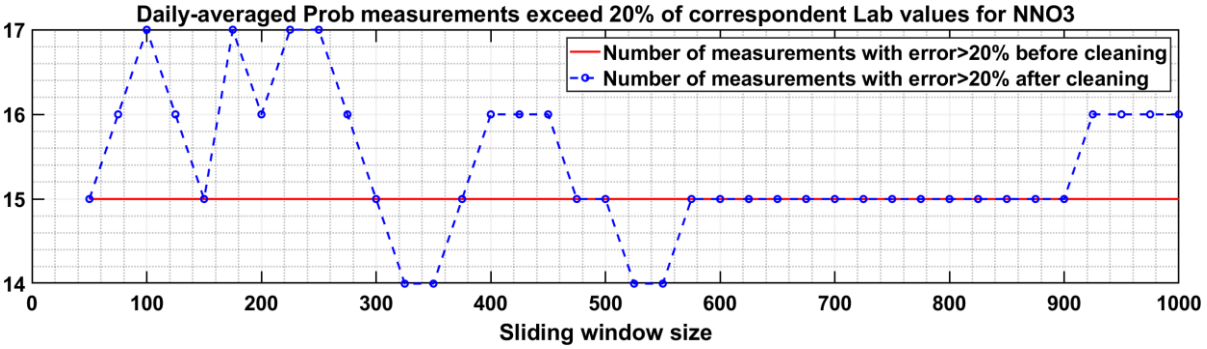

Figure 83. Daily-averaged prob measurements exceed 20% of correspondent Lab values for NNO3

Figure 84. Mean of the errors of prob measurements before and after deleting the outliers for NNO3

Considering window size = 325, the detected outliers out of prob instantaneous measurements are plotted in Figure 85.

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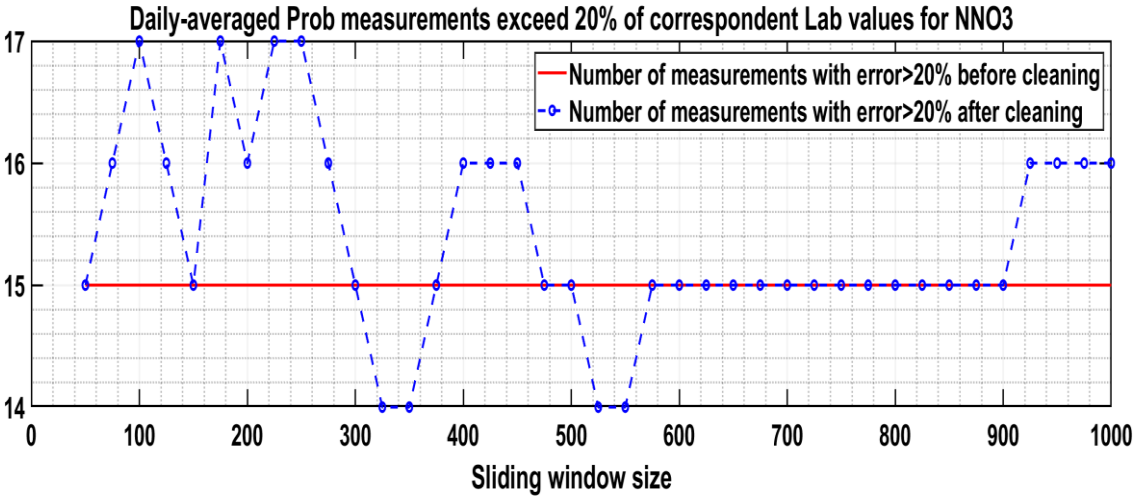

Figure 85. Outliers and Normal instantaneous measurements by prob for selected NNO3 data in 2018; application of M-AAD method

M-MAD performance

M-MAD fails to well capture the outliers as well. The performance of the method in detecting outliers is shown in Figure 86 - Figure 88. However, when the window size is 325, the number of measurements with error >20% is the lowest

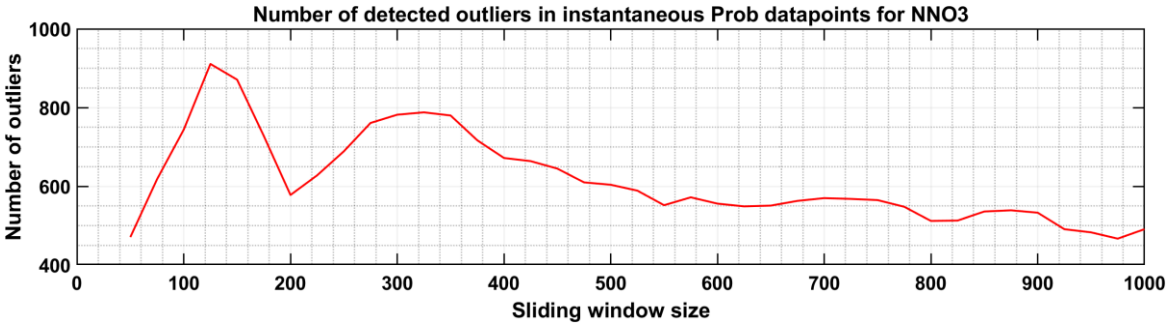

Figure 86. Number of detected outliers in instantaneous prob measurements before and after deleting the outliers for selected NNO3 data points; application of M-MAD method

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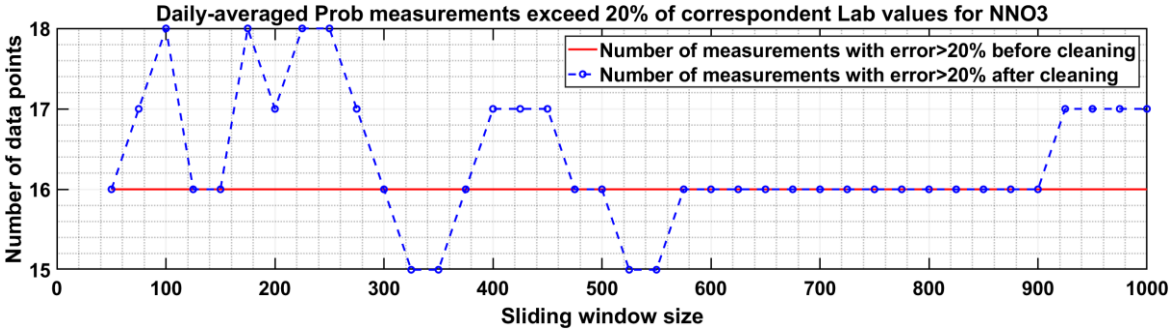

Figure 87. Daily-averaged prob measurements exceed 20% of correspondent Lab values for selected NNO3 data points; application of M-MAD method

Figure 88. Mean of the errors of prob measurements before and after deleting the outliers for selected NNO3 data points; application of M-MAD method

Considering window size = 325, the detected outliers out of prob instantaneous measurements are plotted in Figure 89.

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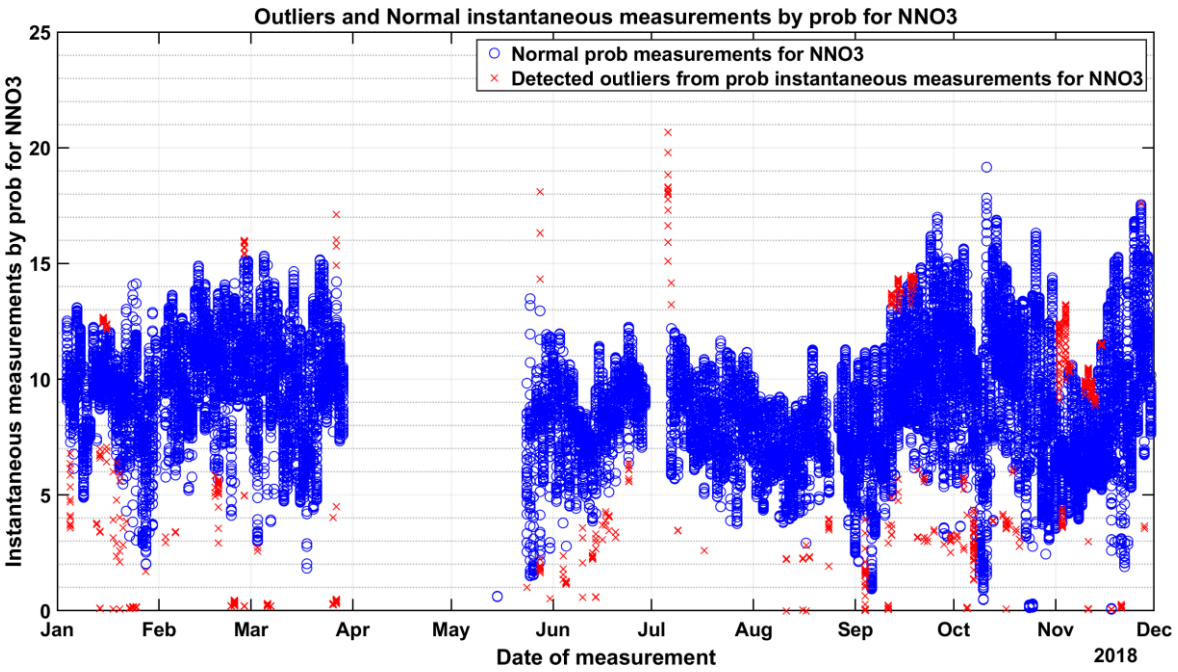

Figure 89: Outliers and Normal instantaneous measurements by prob for selected NNO3 data in 2018; application of M-MAD method

Hotelling's T-squared method

As shown in Figure 90 - Figure 92, the optimal class number is 15 which results in more reduction in mean prob error and amount of data with the error more than 20%. As indicated, implementing T-square method with class number equals to 15 improved the prob measurements accuracy by 5.25% and reduced 14.75% of the datapoints whose error were more than 20%.

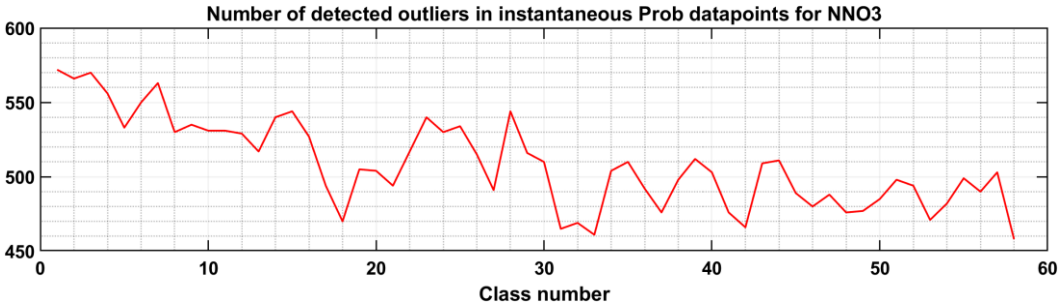

Figure 90. Number of detected outliers V.S. class number in instantaneous Prob datapoints for NNO3

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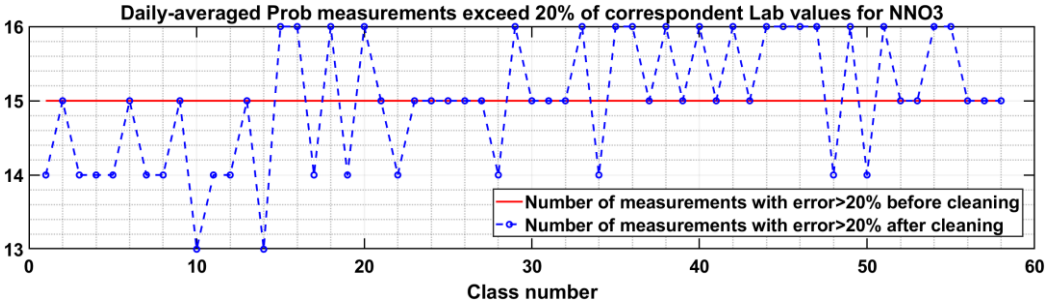

Figure 91. Daily-averaged prob measurements exceed 20% of correspondent Lab values for NNO3

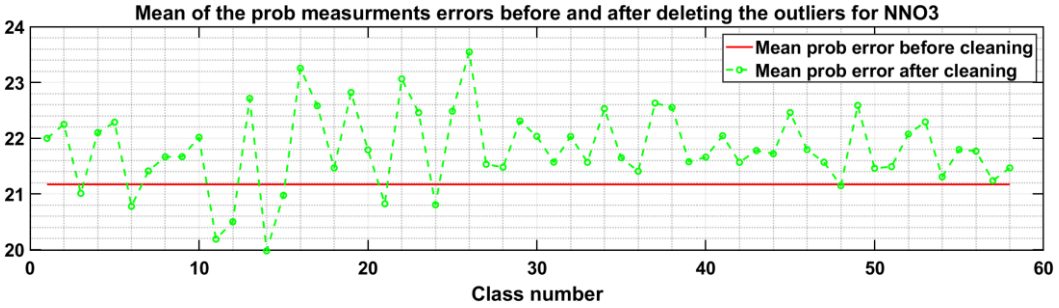

Figure 92. Mean of the errors of prob measurements before and after deleting the outliers for NNO3

Considering class number = 15, the detected outliers out of prob instantaneous measurements are plotted in Figure 93.

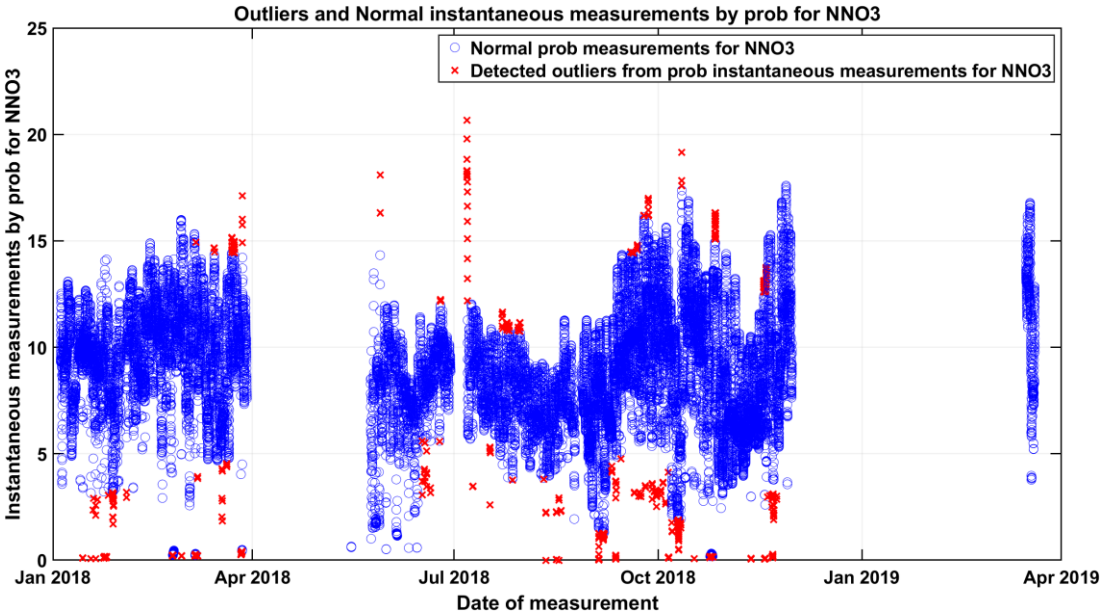

Figure 93: Outliers and Normal instantaneous measurements by prob for NNO3 in 2018-2019

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Integrated T-square and M-SAD

The integrated M-SAD and T-Square method was implemented into the data with window size equal to 325, and class number of the T-square method 15, which were the values that optimized the outlier detection by non-integrated methods. By implementing the integrated method, the number of daily-averaged measurements whose error is more than 20% and the mean prob error were further reduced to 10 and 20.573, respectively. Figure 94 illustrate the normal V.S. detected outliers based on the integrated method.

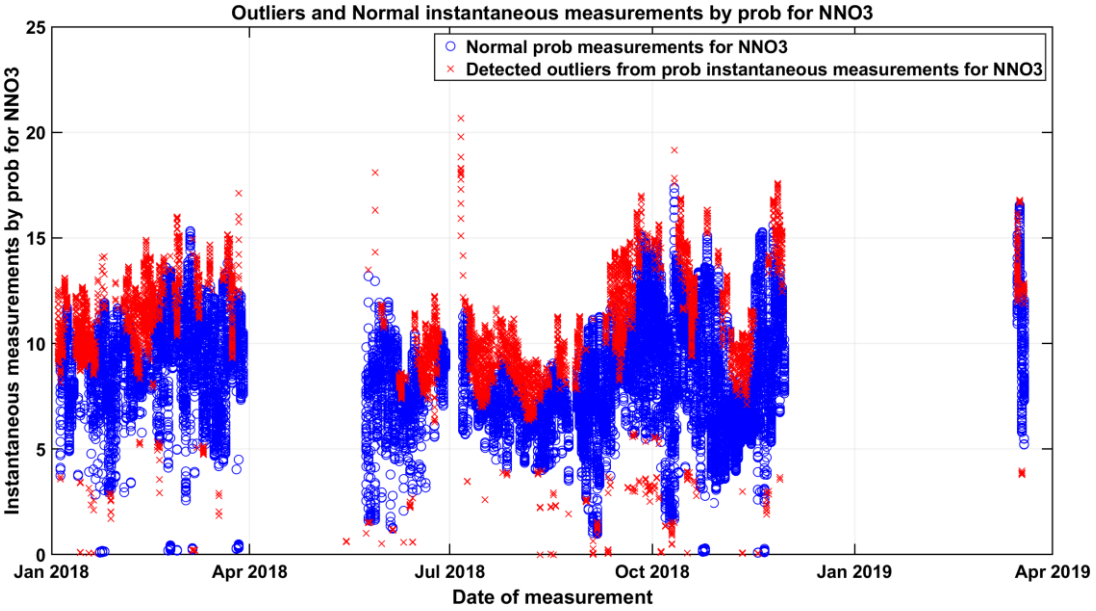

Figure 94. Outliers and Normal instantaneous measurements by prob for NNO3 in 2018-2019

Comparing the performance of various methods in outlier detection of N-NO_3 selected data points

In this section, the performance of different methods implemented to detect the outliers of N-NO_3 instantaneous prob measurements is compared based on statistical indices and diagrams. To do this, the daily-averaged prob records before and after cleaning are compared with those of correspondent lab measurements in terms of Correlation Coefficient (CC), Scatter Index (SI), Root Mean Square Error (RMSE), and BIAS. A detailed explanation for the calculation of the mentioned indexes is provided in Annex C.

As summarized in Table 24, by implementing the integrated MSAD-Tsquare method, the number of daily-averaged measurements whose error is more than 20% reduced from 16 to 10 (37.5 % improvement) and mean prob error reduced from 23.175 to 20.573 (11.23% improvement). Furthermore, statistical indices prove that the integrated method results in more correlation and fewer errors between daily-averaged prob and lab measurements compared to the application of a single method. It should be noted that statistical indices (except standard deviation - std) in Table 24 are calculated based on the daily-averaged prob values concerning lab measurements. It should be noted that the methods should be checked periodically to find out the most optimal window size and class number in moving methods and T-square techniques. This check is suggested to be done each three months when the number of prob instantaneous data points exceed 9000 measurements, which is a sufficient wide set of data.

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Table 24. Statistical indices of prob measurements before and after cleaning with the various method for selected NNO3 data points

	No. of data with error > 20%	Mean prob Error (Eq. 3.24) (%)	Number of detected outliers	Statistical Indices				
				CC	RMSE	SI (%)	BIAS	Std
Before cleaning	16	23.175	-	0.654	2.058	24.81	0.805	2.104
After cleaning using M-SAD	11	21.3023	4861	0.668	1.867	22.45	0.043	2.049
After cleaning using M-AAD	16	23.075	99	0.656	2.056	24.78	0.803	2.117
After cleaning using M-MAD	15	24.639	788	0.671	2.072	24.97	1.007	1.892
After cleaning using T-Square	14	21.902	560	0.705	1.959	23.62	0.896	2.038
After cleaning using integrated method	10	20.573	5098	0.654	1.862	22.45	0.114	1.930

Figure 95 and Figure 96 illustrate the accuracy of daily-averaged prob measurements after deleting the detected outliers by various methods. Inspection of these figures reveals that the integrated MSAD-Tsquare method outperforms others

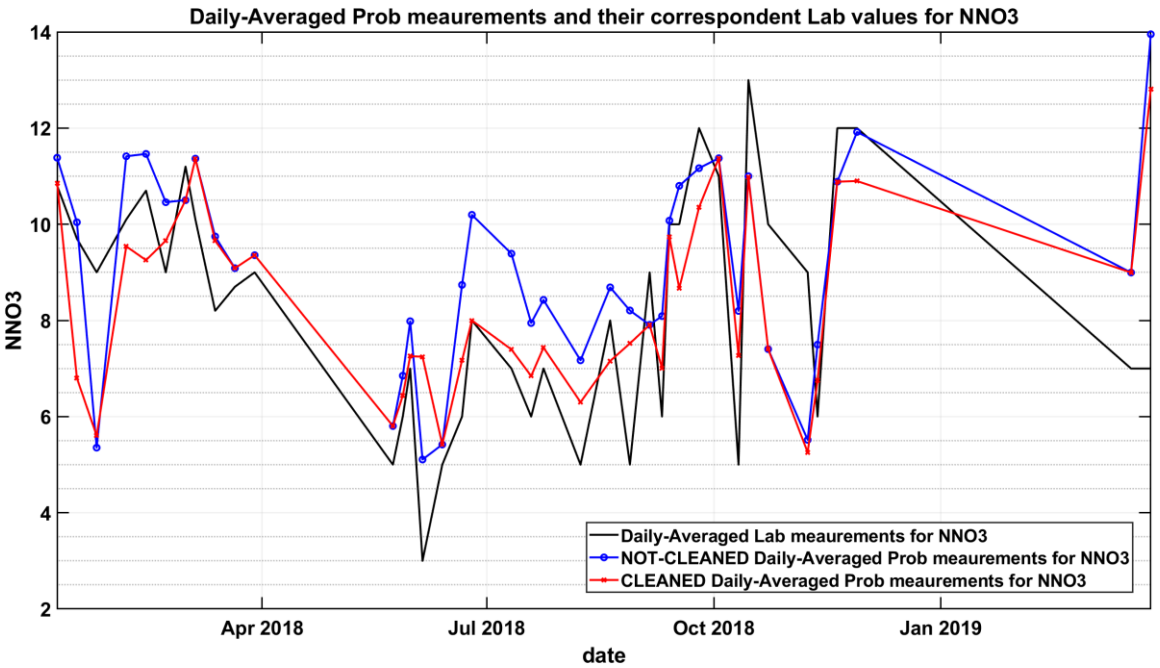

Figure 95. Daily-averaged prob measurements and their correspondent lab values for selected NNO3 data points after cleaning by the integrated method

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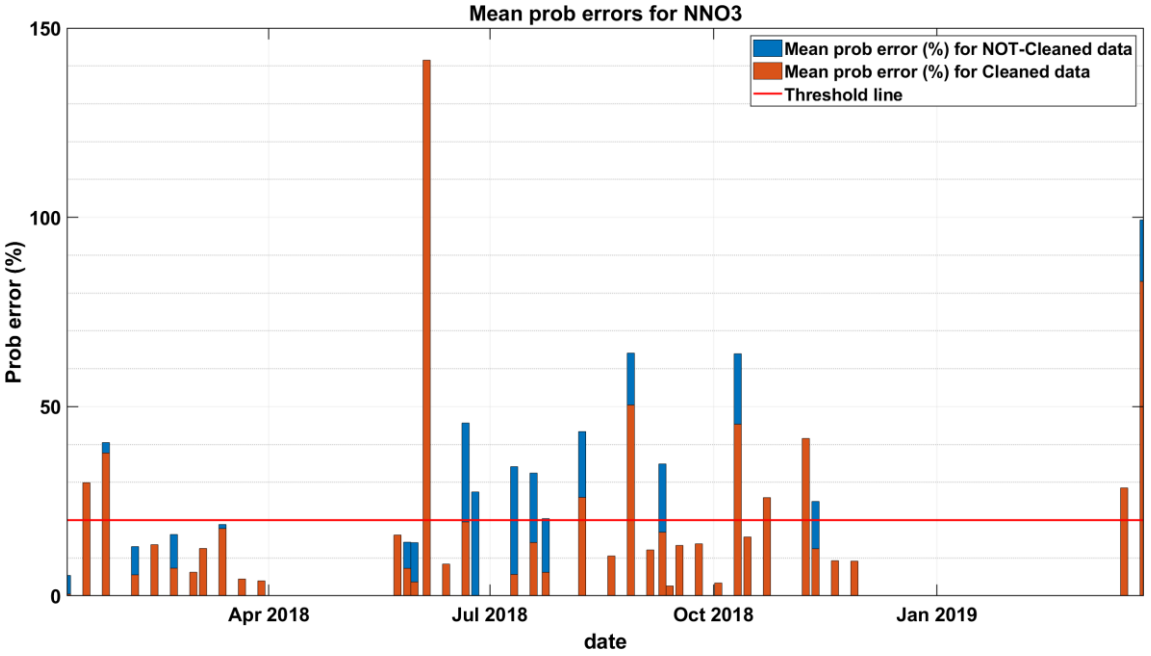

Figure 96. Mean errors of daily-averaged prob measurements concerning their correspondent lab values for selected NNO3 data points after cleaning by the integrated method

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4. Conclusions

In this report, real-time data from sensors were analyzed in order to evaluate their applicability in real-time control systems for water quality monitoring and health risk minimization. Particularly, in this study, sensors networks are designed to provide real-time data to Early Warning Systems, which will be managed to assure health-risk control in three relevant case studies, namely Paris, Berlin and Milan. In the case studies of Paris and Berlin, the monitoring networks aim to reduce the health risks related to microbiological contamination in bathing water sites. In the case study of Milan, the real-time sensor network is designed to promote a safe water reuse, which will reduce the risk of microbial contamination of soils and crops during irrigation. In addition, real-time sensor data will continuously monitor the compliance of wastewater quality with water reuse standard limits.

For monitoring microbiological contamination in water, innovative sensors were tested in this project. The ALERT technology provided by Fluidion for bacteria measurement allows a rapid detection of pathogens, decreasing the response time from the 24-48 hours needed for laboratory analysis to 6-12 hours. Moreover, sampling can be automatized in order to perform periodic measures, even without the presence of operative personnel. When using this new technology, the main obstacle encountered in all the city-cases was the lack of a standardized procedure for the validation of the data coming from the ALERT sensor. Microbiological measures are for their nature not robust (ISO/TR 13843:2000), since they are strictly depending on sample characteristics, variability and heterogeneity, environmental conditions, cultivation method and are affected by personnel operations. Existing guidelines for microbiologic measures are limited to the comparison between analytical lab procedures and aims to validate alternative methods against reference procedures.

Data from ALERT sampling campaigns in Paris, Berlin and Milan were compared with parallel lab measures, using standard methods. Moreover, a repeatability procedure, which consisted in the comparison of ALERT data with laboratory analyses performed by two different laboratories, was conducted in Berlin. Results showed good correlations between ALERT data and laboratory analyses. Three different devices were developed by Fluidion that included a portable device (Alert Lab) and two version of sensors to be installed on site (Alert System V1 and Alert System V2). Performed measurements were consistent between all the three Fluidion devices. Particularly, the updated version of Alert System V2 improved and made significantly easier the maintenance and cleaning procedures between two set of measurements compared to the previous version Alert System V1. In addition, the facilitate cleaning procedure improved the reliability of Alert measurements at low bacteria concentration, which were biased by the presence of disinfectant residue. In the case study of Milan, observed bias between lab and alert measurements was related to the presence of particle materials in wastewater. Such bias was eliminated by the use of appropriate filters.

As regard other monitoring sensors and probes, procedures were developed for the acquisition of more reliable data. In this work, real-time measurements of TSS, NH_4, PO_4 and NO_3 concentrations were processed mathematically to detect outliers in the measurements, and long periods in which the sensor measurements are outside the expected operating range of the system. A mathematical procedure able to identify outliers from sensors signal was developed. To evaluate the bias of the on-line measurements, sensor data were compared with laboratory analyses. It was noted that the developed cleaning procedure significantly reduced the bias of data compared to the raw (uncleaned) data. However, periodical maintenance and cleaning of sensor probes appeared to be fundamental to get reliable data.

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Once online sensors provide reliable data, their signals can be used to implement water reuse risk management plan. In particular, the monitoring network will support the Early Warning System, in order to provide a rapid detection of possible incoming hazardous events. The inclusion of continuous monitoring and their integration into the EWS will reduce the likelihood of the occurrence of hazardous outcomes for exposed population since they allow rapid interventions and decision support to minimize risks. Moreover, the water reuse risk management plan will be developed in D1.3, considering the requirements of the new EU Regulation 741/2020, and in line with the international US-EPA and Australian guidelines. Sensors' data and EWS will be integrated in the system as control measures to reduce risks. In this perspective, sensors maintenance, monitoring and verification procedures will be planned in order to guarantee the effectiveness of the applied control measures.

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Annex A

Collected ALERT data during the monitoring campaign in Paris in 2019 are reported in Table A1. ALERT data collected during the monitoring campaign in Milan in 2019 are reported in Table A2. Alert data collected during the monitoring campaigns in Berlin in 2019 and 2020 are reported in Table A3 and Table A4. The 2021 campaign data using ALERT V2 from Paris is shown in Table A5, from Milan in Tables A6-A7 and from Berlin in Table A8.

Table A1: Data from sampling campaign with ALERT System and ALERT LAB in Paris

Sampling date and time	field label	Lab count (MPN/100ml)	E. Coli Fluidion	ln difference	Log(FLD)-Log(NPP)
9/22/19 13:43	CHOI50 TP01-01	14,300	221,885	2.74E+00	1.19E+00
9/22/19 14:43	CHOI50 TP01-02	6,330	499,018	4.37E+00	1.90E+00
9/22/19 15:43	CHOI50 TP01-03	8,650	959,350	4.71E+00	2.04E+00
8/21/19 11:52	Marne Spatial Camp 1-01	633	1175	6.19E-01	2.69E-01
8/21/19 11:54	Marne Spatial Camp 1-02	1,120	1804	4.77E-01	2.07E-01
8/21/19 11:58	Marne Spatial Camp 1-03	591	1332	8.13E-01	3.53E-01
8/21/19 12:03	Marne Spatial Camp 1-04	882	1114	2.34E-01	1.01E-01
8/21/19 12:05	Marne Spatial Camp 1-05	930	1741	6.27E-01	2.72E-01
8/21/19 12:08	Marne Spatial Camp 1-06	1,180	2008	5.32E-01	2.31E-01
8/21/19 12:11	Marne Spatial Camp 1-07	750	1356	5.92E-01	2.57E-01
8/21/19 12:13	Marne Spatial Camp 1-08	675	1285	6.44E-01	2.80E-01
8/21/19 12:17	Marne Spatial Camp 1-09	882	1285	3.76E-01	1.63E-01
8/21/19 12:19	Marne Spatial Camp 1-10	1,100	3685	1.21E+00	5.25E-01
8/21/19 12:21	Marne Spatial Camp 1-11	1,180	2316	6.74E-01	2.93E-01
8/21/19 12:24	Marne Spatial Camp 1-12	1,300	4176	1.17E+00	5.07E-01
8/28/19 10:42	Marne Spatial Camp 2-01	909	2488	1.01E+00	4.37E-01
8/28/19 10:52	Marne Spatial Camp 2-02	1,100	2081	6.38E-01	2.77E-01
8/28/19 10:56	Marne Spatial Camp 2-03	782	2044	9.61E-01	4.17E-01
8/28/19 10:58	Marne Spatial Camp 2-04	1,360	1741	2.47E-01	1.07E-01
8/28/19 11:00	Marne Spatial Camp 2-05	1,640	1285	-2.44E-01	-1.06E-01
8/28/19 11:02	Marne Spatial Camp 2-06	1,590	2672	5.19E-01	2.25E-01
8/28/19 11:04	Marne Spatial Camp 2-07	1,720	1837	6.58E-02	2.86E-02
8/28/19 11:06	Marne Spatial Camp 2-08	742	1332	5.85E-01	2.54E-01
8/28/19 11:10	Marne Spatial Camp 2-09	1,260	3751	1.09E+00	4.74E-01
8/28/19 11:12	Marne Spatial Camp 2-10	1,470	4251	1.06E+00	4.61E-01
8/28/19 11:20	Marne Spatial Camp 2-11	640	2358	1.30E+00	5.66E-01
8/28/19 11:22	Marne Spatial Camp 2-12	1,320	1482	1.16E-01	5.03E-02
9/22/19 20:15	Marne TP02-02	34,700	34300	-1.16E-02	-5.04E-03
9/23/19 2:15	Marne TP02-03	8,330	3311	-9.23E-01	-4.01E-01

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9/23/19 8:15	Marne TP02-04	4,570	5082	1.06E-01	4.61E-02
9/23/19 20:15	Marne TP02-06	3,040	1536	-6.83E-01	-2.96E-01
9/24/19 2:15	Marne TP02-07	3,300	1804	-6.04E-01	-2.62E-01
9/24/19 17:01	Marne TP02-08	11,600	6,884	-5.22E-01	-2.27E-01
9/29/19 12:30	Marne TP03-02	7,100	6,884	-3.09E-02	-1.34E-02
9/29/19 14:30	Marne TP03-03	15,200	7,941	-6.49E-01	-2.82E-01
9/29/19 18:32	Marne TP03-04	7,100	5,968	-1.74E-01	-7.54E-02
10/1/19 12:00	Marne TP03-10	1,439	1,804	2.26E-01	9.82E-02
10/1/19 18:00	Marne TP03-12	1,842	1,564	-1.64E-01	-7.11E-02
10/8/19 18:00	Marne TP04-05	20,684	5,968	-1.24E+00	-5.40E-01
10/9/19 0:01	Marne TP04-06	15,626	3,819	-1.41E+00	-6.12E-01
10/9/19 6:01	Marne TP04-07	5,364	5,758	7.09E-02	3.08E-02
10/9/19 12:00	Marne TP04-08	34,700	41,057	1.68E-01	7.31E-02
10/9/19 18:00	Marne TP04-09	5,040	2,819	-5.81E-01	-2.52E-01
10/10/19 0:00	Marne TP04-10	15,200	6,884	-7.92E-01	-3.44E-01
10/10/19 6:00	Marne TP04-11	9,830	3,252	-1.11E+00	-4.80E-01
10/10/19 12:00	Marne TP04-12	4,180	2,444	-5.37E-01	-2.33E-01
10/10/19 18:00	Marne TP04-13	2,160	263	-2.11E+00	-9.14E-01
10/11/19 0:00	Marne TP04-14	2,810	1,356	-7.29E-01	-3.16E-01
8/6/19 15:49	SB TP01-1	6,700,000	337,132	-2.99E+00	-1.30E+00
8/6/19 16:18	SB TP01-2	1,760,000	175,363	-2.31E+00	-1.00E+00
8/6/19 16:48	SB TP01-3	313,000	115,015	-1.00E+00	-4.35E-01
8/6/19 17:18	SB TP01-4	783,000	1,457,633	6.21E-01	2.70E-01
8/6/19 17:48	SB TP01-5	1,410,000	1,796,734	2.42E-01	1.05E-01
8/6/19 18:18	SB TP01-6	1,410,000	3,111,194	7.91E-01	3.44E-01
10/1/19 17:46	SB TP04-01	2,492,215	1,943,332	-2.49E-01	-1.08E-01
10/1/19 18:31	SB TP04-02	5,358,410	4,486,311	-1.78E-01	-7.71E-02
10/1/19 19:16	SB TP04-03	4,915,874	8,624,832	5.62E-01	2.44E-01
10/1/19 20:01	SB TP04-04	3,246,245	4,257,753	2.71E-01	1.18E-01
10/1/19 20:46	SB TP04-05	2,594,262	5,387,292	7.31E-01	3.17E-01
10/1/19 21:31	SB TP04-06	7,883,425	8,185,434	3.76E-02	1.63E-02
10/8/19 4:09	SB TP05-1	3,167,800	1,457,633	-7.76E-01	-3.37E-01
10/8/19 5:09	SB TP05-2	1,445,842	864,091	-5.15E-01	-2.24E-01
10/8/19 6:09	SB TP05-3	702,265	499,018	-3.42E-01	-1.48E-01
10/8/19 7:09	SB TP05-4	920,360	798,906	-1.42E-01	-6.15E-02
10/8/19 8:09	SB TP05-5	1,278,174	758,206	-5.22E-01	-2.27E-01
10/8/19 10:09	SB TP05-6	2,081,379	2,047,651	-1.63E-02	-7.10E-03

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8/26/19 8:00	Seine 24hTS1 1	619	303	-7.14E-01	-3.10E-01
9/2/19 8:00	Seine 24hTS2 1	1,390	1564	1.18E-01	5.12E-02
9/4/19 8:57	Seine Spatial Camp 1-01	1,370	752	-6.00E-01	-2.61E-01
9/4/19 9:00	Seine Spatial Camp 1-02	1,260	739	-5.34E-01	-2.32E-01
9/4/19 9:02	Seine Spatial Camp 1-03	1,400	823	-5.31E-01	-2.31E-01
9/4/19 9:04	Seine Spatial Camp 1-04	1,380	726	-6.42E-01	-2.79E-01
9/4/19 9:07	Seine Spatial Camp 1-05	1,750	1509	-1.48E-01	-6.43E-02
9/4/19 9:11	Seine Spatial Camp 1-06	1,790	1973	9.73E-02	4.23E-02
9/4/19 9:15	Seine Spatial Camp 1-07	1,320	1564	1.70E-01	7.37E-02
9/4/19 9:18	Seine Spatial Camp 1-08	1,300	1536	1.67E-01	7.24E-02
9/4/19 9:20	Seine Spatial Camp 1-09	1,050	1772	5.23E-01	2.27E-01
9/4/19 9:22	Seine Spatial Camp 1-10	1,150	837	-3.18E-01	-1.38E-01
9/4/19 9:24	Seine Spatial Camp 1-11	1,170	794	-3.88E-01	-1.68E-01
9/4/19 9:29	Seine Spatial Camp 1-12	1,310	1680	2.49E-01	1.08E-01
9/18/19 8:41	Seine Spatial Camp 2-01	838	1356	4.81E-01	2.09E-01
9/18/19 8:44	Seine Spatial Camp 2-02	434	739	5.32E-01	2.31E-01
9/18/19 8:46	Seine Spatial Camp 2-03	524	837	4.68E-01	2.03E-01
9/18/19 8:47	Seine Spatial Camp 2-04	375	618	5.00E-01	2.17E-01
9/18/19 8:49	Seine Spatial Camp 2-05	647	713	9.71E-02	4.22E-02
9/18/19 8:51	Seine Spatial Camp 2-06	728	1094	4.07E-01	1.77E-01
9/18/19 8:54	Seine Spatial Camp 2-07	896	1019	1.29E-01	5.59E-02
9/18/19 8:56	Seine Spatial Camp 2-08	791	868	9.29E-02	4.03E-02
9/18/19 8:59	Seine Spatial Camp 2-09	668	1804	9.93E-01	4.31E-01
9/18/19 9:01	Seine Spatial Camp 2-10	764	1509	6.81E-01	2.96E-01
9/18/19 9:03	Seine Spatial Camp 2-11	805	618	-2.64E-01	-1.15E-01
9/18/19 9:05	Seine Spatial Camp 2-12	640	1262	6.79E-01	2.95E-01
8/8/19 23:23	Seine TP01-07	1,680	1155	-3.75E-01	-1.63E-01
9/23/19 6:01	Seine TP02-02	4,750	146	-3.48E+00	-1.51E+00
9/30/19 3:00	Seine TP03-01	559	263	-7.54E-01	-3.27E-01
9/30/19 9:00	Seine TP03-02	720	555	-2.60E-01	-1.13E-01
10/1/19 12:00	Seine TP03-07	1,150	1,155	4.34E-03	1.88E-03
10/8/19 12:00	Seine TP04-01	969	868	-1.10E-01	-4.78E-02
10/8/19 18:01	Seine TP04-02	1,500	739	-7.08E-01	-3.07E-01
10/9/19 0:00	Seine TP04-03	3,040	555	-1.70E+00	-7.39E-01
10/9/19 6:01	Seine TP04-04	2,720	1,155	-8.57E-01	-3.72E-01
10/9/19 12:00	Seine TP04-05	16,700	5,968	-1.03E+00	-4.47E-01

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Table A2: Data from sampling campaign with ALERT LAB in Milan

Sampling date	Label	Lab count CFU/100 mL	FLUIDION CFU/100 mL	Ln difference	Log10 difference
10/01/2019	IN-BIO-020	9.00E+06	1.29E+08	2.66	1.16
10/01/2019	IN-UV-020	6.40E+03	1.74E+05	3.30	1.43
10/01/2019	OUT-UV-020	4.05E+02	1.24E+02	-1.18	-0.51
10/02/2019	IN-BIO-021	2.00E+07	2.29E+06	-2.17	-0.94
10/02/2019	IN-UV-021	6.35E+03	8.81E+03	0.33	0.14
10/02/2019	OUT-UV-021	435	3	-4.93	-2.14
10/03/2019	IN-PAA-001	3.15E+04	2.64E+04	-0.18	-0.08
10/03/2019	OUT-PAA-001	4.20E+02	2.89E+02	-0.37	-0.16
10/10/2019	IN-BIO-022	1.46E+08	2.33E+07	-1.83	-0.80
10/10/2019	IN-UV-022	3.70E+03	9.04E+03	0.89	0.39
10/10/2019	OUT-UV-022	1.40E+02	2.35E+02	0.52	0.23
10/14/2019	IN-BIO-023	1.15E+07	4.34E+06	-0.98	-0.42
10/14/2019	IN-UV-023	1.55E+03	4.66E+03	1.10	0.48
10/14/2019	OUT-UV-023	49	1	-4.17	-1.81
10/17/2019	IN-BIO-024	6.40E+06	2.81E+06	-0.82	-0.36
10/17/2019	IN-UV-024	1.90E+04	2.10E+04	0.10	0.04
10/17/2019	OUT-UV-024	38	1	-3.92	-1.70
10/17/2019	IN-BIO-025	6.40E+06	1.41E+06	-1.51	-0.66
10/17/2019	IN-UV-025	1.90E+04	1.58E+04	-0.18	-0.08
10/17/2019	OUT-UV-025	38	14	-0.98	-0.43
10/23/2019	IN-BIO-026	1.04E+07	1.05E+08	2.32	1.01
10/23/2019	IN-UV-026	6.80E+03	1.13E+05	2.81	1.22
10/23/2019	OUT-UV-026	20	18	-0.09	-0.04
10/28/2019	IN-UV-027	5.90E+03	3.61E+03	-0.49	-0.21
10/28/2019	OUT-UV-027	36.5	43	0.15	0.07
10/28/2019	IN-UV-028	5.90E+03	1.55E+03	-1.33	-0.58
10/28/2019	OUT-UV-028	36.5	178	1.58	0.69
10/30/2019	IN-BIO-031	1.00E+07	9.32E+06	-0.07	-0.03
10/30/2019	IN-UV-031	1.85E+03	1.05E+04	1.74	0.76
10/30/2019	OUT-UV-031	47.5	51	0.07	0.03
10/30/2019	IN-UV-032	1.85E+03	3.99E+03	0.77	0.33
10/30/2019	OUT-UV-032	47.5	2	-3.45	-1.50
11/05/2019	IN-BIO-033	4.15E+07	3.45E+06	-2.49	-1.08
11/05/2019	IN-UV-033	7.40E+03	1.05E+04	0.35	0.15
11/05/2019	OUT-UV-033	11	0	-11.55	-5.02
11/05/2019	IN-BIO-034	4.15E+07	1.64E+06	-3.23	-1.40
11/05/2019	IN-UV-034	7.40E+03	1.51E+04	0.71	0.31
11/05/2019	OUT-UV-034	11	0	-11.55	-5.02

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11/13/2019	IN-BIO-037	6.10E+05	1.15E+06	0.63	0.28
11/13/2019	IN-UV-037	1.10E+03	3.61E+03	1.19	0.52
11/13/2019	OUT-UV-037	1.5	0	-9.56	-4.15
11/13/2019	IN-BIO-038	6.10E+05	1.48E+06	0.89	0.39
11/13/2019	IN-UV-038	1.10E+03	5.71E+03	1.65	0.72
11/13/2019	OUT-UV-038	1.5	0	-9.56	-4.15
11/21/2019	IN-OXI-004	5.85E+05	9.45E+04	-1.82	-0.79
11/21/2019	IN-PAA-004	7.05E+03	3.87E+04	1.70	0.74
11/21/2019	OUT-PAA-004	31	0	-12.59	-5.47
11/21/2019	IN-BIO-039	1.60E+07	1.38E+06	-2.45	-1.07
11/21/2019	IN-UV-039	3.50E+03	4.42E+03	0.23	0.10
11/21/2019	OUT-UV-039	18	17	-0.08	-0.04
11/25/2019	IN-OXI-005	3.50E+04	5.53E+04	0.46	0.20
11/25/2019	IN-PAA-005	2.55E+03	2.92E+04	2.44	1.06
11/25/2019	OUT-PAA-005	7.5	20	1.00	0.43
11/25/2019	IN-BIO-040	4.75E+05	2.41E+06	1.62	0.71
11/25/2019	IN-UV-040	5.50E+02	1.67E+04	3.41	1.48
11/25/2019	OUT-UV-040	1	0	-9.16	-3.98
12/12/2019	IN-BIO-042	4.80E+07	7.50E+08	2.75	1.19
12/12/2019	IN-UV-042	2.75E+03	9.15E+05	5.81	2.52
12/12/2019	OUT-UV-042	21.5	5.32E+02	3.21	1.39
12/12/2019	IN-BIO-043	4.80E+07	1.23E+04	-8.27	-3.59
12/12/2019	IN-UV-043	2.75E+03	1.07E+06	5.96	2.59
12/12/2019	OUT-UV-043	21.5	2.48E+02	2.44	1.06
16/12/2019	IN-UV-044	1.85E+03	9.04E+03	1.59	0.69
16/12/2019	IN-UV-045	7.00E+02	1.59E+03	0.82	0.36
16/12/2019	IN-UV-046	7.00E+02	0	-8.10	-3.52
16/12/2019	OUT-UV-044	0.5	8.37E+03	9.73	4.22
16/12/2019	OUT-UV-045	1.5	0	-3.92	-1.70
16/12/2019	OUT-UV-046	1.5	2	0.49	0.21

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Table A3: Data from Spree river sampling campaigns 2019-2020 in Berlin (ALERT SYSTEM, ALERT LAB, ALERT LAB TC)

Sampling date	Label	Count CFU/100 mL	Log10 (count)
17/06/2020 00:00	ALERT_Lab_1.1		
17/06/2020 00:00	ALERT_Lab_1.2		
17/06/2020 00:00	ALERT_Lab_2.1		
17/06/2020 00:00	ALERT_Lab_2.2		
17/06/2020 09:57	ALERT_Lab_2.1_TC	212	2.326335861
17/06/2020 09:57	ALERT_Lab_2.2_TC	112	2.049218023
17/06/2020 09:46	ALERT_Sys_1	258	2.411619706
17/06/2020 09:59	ALERT_Sys_2	228	2.357934847
17/06/2020 09:47	LAB_1.1	215	2.33243846
17/06/2020 09:47	LAB_1.2	253	2.403120521
17/06/2020 09:57	LAB_2.1	213	2.328379603
17/06/2020 09:57	LAB_2.2	327	2.514547753
18/06/2020 10:47	ALERT_Lab_1.1	320	2.505149978
18/06/2020 10:47	ALERT_Lab_1.2	425	2.62838893
18/06/2020 10:56	ALERT_Lab_2.1	356	2.551449998
18/06/2020 10:56	ALERT_Lab_2.2	232	2.365487985
18/06/2020 10:56	ALERT_Lab_2.1_TC	331	2.519827994
18/06/2020 10:56	ALERT_Lab_2.2_TC	325	2.511883361
18/06/2020 00:00	ALERT_Sys_1		
18/06/2020 10:56	ALERT_Sys_2	739	2.868644438
18/06/2020 10:47	LAB_1.1	330	2.51851394
18/06/2020 10:47	LAB_1.2	332	2.521138084
18/06/2020 10:56	LAB_2.1	177	2.247973266
18/06/2020 10:56	LAB_2.2	292	2.465382851
19/06/2020 11:21	ALERT_Lab_1.1	149	2.173186268
19/06/2020 11:21	ALERT_Lab_1.2	220	2.342422681
19/06/2020 11:32	ALERT_Lab_2.1	287	2.457881897
19/06/2020 11:32	ALERT_Lab_2.2	159	2.201397124
19/06/2020 11:32	ALERT_Lab_2.1_TC	127	2.103803721
19/06/2020 11:32	ALERT_Lab_2.2_TC	162	2.209515015
19/06/2020 00:00	ALERT_Sys_1		
19/06/2020 00:00	ALERT_Sys_2		
19/06/2020 11:21	LAB_1.1	249	2.396199347
19/06/2020 11:21	LAB_1.2	144	2.158362492
19/06/2020 11:32	LAB_2.1	212	2.326335861
19/06/2020 11:32	LAB_2.2	213	2.328379603
22/06/2020 10:20	ALERT_Lab_1.1	490	2.69019608
22/06/2020 10:20	ALERT_Lab_1.2	308	2.488550717
22/06/2020 10:34	ALERT_Lab_2.1	349	2.542825427
22/06/2020 10:34	ALERT_Lab_2.2	258	2.411619706
22/06/2020 10:34	ALERT_Lab_2.1_TC	536	2.72916479
22/06/2020 10:34	ALERT_Lab_2.2_TC	240	2.380211242
22/06/2020 10:33	ALERT_Sys_1	95	1.977723605
22/06/2020 10:35	ALERT_Sys_2	191	2.281033367
22/06/2020 10:20	LAB_1.1	375	2.574031268
22/06/2020 10:20	LAB_1.2	143	2.155336037
22/06/2020 10:34	LAB_2.1	289	2.460897843

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22/06/2020 10:34	LAB_2.2	368	2.565847819
23/06/2020 10:29	ALERT_Lab_1.1	314	2.496929648
23/06/2020 10:29	ALERT_Lab_1.2	308	2.488550717
23/06/2020 10:38	ALERT_Lab_2.1	224	2.350248018
23/06/2020 10:38	ALERT_Lab_2.2	343	2.53529412
23/06/2020 10:38	ALERT_Lab_2.1_TC	473	2.674861141
23/06/2020 10:38	ALERT_Lab_2.2_TC	465	2.667452953
23/06/2020 10:30	ALERT_Sys_1	418	2.621176282
23/06/2020 10:38	ALERT_Sys_2	362	2.558708571
23/06/2020 10:29	LAB_1.1	332	2.521138084
23/06/2020 10:29	LAB_1.2	253	2.403120521
23/06/2020 10:38	LAB_2.1	312	2.494154594
23/06/2020 10:38	LAB_2.2	253	2.403120521
24/06/2020 00:00	ALERT_Lab_1.1		
24/06/2020 00:00	ALERT_Lab_1.2		
24/06/2020 11:42	ALERT_Lab_2.1	267	2.426511261
24/06/2020 11:42	ALERT_Lab_2.2	228	2.357934847
24/06/2020 11:42	ALERT_Lab_2.1_TC	249	2.396199347
24/06/2020 11:42	ALERT_Lab_2.2_TC	187	2.271841607
24/06/2020 00:00	ALERT_Sys_1		
24/06/2020 00:00	ALERT_Sys_2		
24/06/2020 00:00	LAB_1.1		
24/06/2020 00:00	LAB_1.2		
24/06/2020 11:42	LAB_2.1	330	2.51851394
24/06/2020 11:42	LAB_2.2	287	2.457881897
25/06/2020 12:40	ALERT_Lab_1.1	149	2.173186268
25/06/2020 12:40	ALERT_Lab_1.2	224	2.350248018
25/06/2020 12:50	ALERT_Lab_2.1	174	2.240549248
25/06/2020 12:50	ALERT_Lab_2.2	171	2.23299611
25/06/2020 12:50	ALERT_Lab_2.1_TC	168	2.225309282
25/06/2020 12:50	ALERT_Lab_2.2_TC	138	2.139879086
25/06/2020 12:40	ALERT_Sys_1	473	2.674861141
25/06/2020 12:48	ALERT_Sys_2	69	1.838849091
25/06/2020 12:40	LAB_1.1	312	2.494154594
25/06/2020 12:40	LAB_1.2	268	2.428134794
25/06/2020 12:50	LAB_2.1	253	2.403120521
25/06/2020 12:50	LAB_2.2	272	2.434568904
26/06/2020 09:48	ALERT_Lab_1.1	110	2.041392685
26/06/2020 09:48	ALERT_Lab_1.2	263	2.419955748
26/06/2020 09:58	ALERT_Lab_2.1	151	2.178976947
26/06/2020 09:58	ALERT_Lab_2.2	69	1.838849091
26/06/2020 09:58	ALERT_Lab_2.1_TC	240	2.380211242
26/06/2020 09:58	ALERT_Lab_2.2_TC	263	2.419955748
26/06/2020 00:00	ALERT_Sys_1		
26/06/2020 00:00	ALERT_Sys_2		
26/06/2020 09:48	LAB_1.1	159	2.201397124
26/06/2020 09:48	LAB_1.2	94	1.973127854
26/06/2020 09:58	LAB_2.1	213	2.328379603
26/06/2020 09:58	LAB_2.2	77	1.886490725

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29/06/2020 12:08	ALERT_Lab_1.1	27	1.431363764
29/06/2020 12:08	ALERT_Lab_1.2	106	2.025305865
29/06/2020 12:18	ALERT_Lab_2.1	136	2.133538908
29/06/2020 12:18	ALERT_Lab_2.2	24	1.380211242
29/06/2020 12:18	ALERT_Lab_2.1_TC	112	2.049218023
29/06/2020 12:18	ALERT_Lab_2.2_TC	38	1.579783597
29/06/2020 12:09	ALERT_Sys_1	10	1
29/06/2020 12:18	ALERT_Sys_2	410	2.612783857
29/06/2020 12:08	LAB_1.1	77	1.886490725
29/06/2020 12:08	LAB_1.2	126	2.100370545
29/06/2020 12:18	LAB_2.1	160	2.204119983
29/06/2020 12:18	LAB_2.2	61	1.785329835
30/06/2020 10:21	ALERT_Lab_1.1	83	1.919078092
30/06/2020 10:21	ALERT_Lab_1.2	205	2.311753861
30/06/2020 10:31	ALERT_Lab_2.1	197	2.294466226
30/06/2020 10:31	ALERT_Lab_2.2	57	1.755874856
30/06/2020 10:31	ALERT_Lab_2.1_TC	212	2.326335861
30/06/2020 10:31	ALERT_Lab_2.2_TC	133	2.123851641
30/06/2020 00:00	ALERT_Sys_1		
30/06/2020 10:31	ALERT_Sys_2	60	1.77815125
30/06/2020 10:21	LAB_1.1	143	2.155336037
30/06/2020 10:21	LAB_1.2	127	2.103803721
30/06/2020 10:31	LAB_2.1	143	2.155336037
30/06/2020 10:31	LAB_2.2	160	2.204119983
01/07/2020 11:02	ALERT_Lab_1.1	433	2.636487896
01/07/2020 11:02	ALERT_Lab_1.2	425	2.62838893
01/07/2020 11:10	ALERT_Lab_2.1	308	2.488550717
01/07/2020 11:10	ALERT_Lab_2.2	232	2.365487985
01/07/2020 11:10	ALERT_Lab_2.1_TC	116	2.064457989
01/07/2020 11:10	ALERT_Lab_2.2_TC	99	1.995635195
01/07/2020 11:03	ALERT_Sys_1	258	2.411619706
01/07/2020 11:11	ALERT_Sys_2	403	2.605305046
01/07/2020 11:02	LAB_1.1	160	2.204119983
01/07/2020 11:02	LAB_1.2	142	2.152288344
01/07/2020 11:10	LAB_2.1	234	2.369215857
01/07/2020 11:10	LAB_2.2	144	2.158362492
02/07/2020 00:00	ALERT_Lab_1.1		
02/07/2020 00:00	ALERT_Lab_1.2		
02/07/2020 00:00	ALERT_Lab_2.1		
02/07/2020 00:00	ALERT_Lab_2.2		
02/07/2020 10:39	ALERT_Lab_2.1_TC	157	2.195899652
02/07/2020 10:39	ALERT_Lab_2.2_TC	282	2.450249108
02/07/2020 10:29	ALERT_Sys_1	99	1.995635195
02/07/2020 10:44	ALERT_Sys_2	652	2.814247596
02/07/2020 10:29	LAB_1.1	93	1.968482949
02/07/2020 10:29	LAB_1.2	161	2.206825876
02/07/2020 10:39	LAB_2.1	197	2.294466226
02/07/2020 10:39	LAB_2.2	232	2.365487985
03/07/2020 09:37	ALERT_Lab_1.1	253	2.403120521

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03/07/2020 09:37	ALERT_Lab_1.2	120	2.079181246
03/07/2020 10:20	ALERT_Lab_2.1	136	2.133538908
03/07/2020 10:20	ALERT_Lab_2.2	362	2.558708571
03/07/2020 10:20	ALERT_Lab_2.1_TC	181	2.257678575
03/07/2020 10:20	ALERT_Lab_2.2_TC	133	2.123851641
03/07/2020 12:58	ALERT_Sys_1	389	2.589949601
03/07/2020 00:00	ALERT_Sys_2		
03/07/2020 09:37	LAB_1.1	94	1.973127854
03/07/2020 09:37	LAB_1.2	144	2.158362492
03/07/2020 10:20	LAB_2.1	143	2.155336037
03/07/2020 10:20	LAB_2.2	127	2.103803721
06/07/2020 10:15	ALERT_Lab_1.1	205	2.311753861
06/07/2020 10:15	ALERT_Lab_1.2	177	2.247973266
06/07/2020 10:25	ALERT_Lab_2.1	171	2.23299611
06/07/2020 10:25	ALERT_Lab_2.2	129	2.11058971
06/07/2020 10:25	ALERT_Lab_2.1_TC	104	2.017033339
06/07/2020 10:25	ALERT_Lab_2.2_TC	157	2.195899652
06/07/2020 10:16	ALERT_Sys_1	349	2.542825427
06/07/2020 10:26	ALERT_Sys_2	21	1.322219295
06/07/2020 10:15	LAB_1.1	161	2.206825876
06/07/2020 10:15	LAB_1.2	126	2.100370545
06/07/2020 10:25	LAB_2.1	94	1.973127854
06/07/2020 10:25	LAB_2.2	234	2.369215857
07/07/2020 10:07	ALERT_Lab_1.1	410	2.612783857
07/07/2020 10:07	ALERT_Lab_1.2	194	2.28780173
07/07/2020 10:17	ALERT_Lab_2.1	253	2.403120521
07/07/2020 10:17	ALERT_Lab_2.2	216	2.334453751
07/07/2020 10:17	ALERT_Lab_2.1_TC	197	2.294466226
07/07/2020 10:17	ALERT_Lab_2.2_TC	171	2.23299611
07/07/2020 10:08	ALERT_Sys_1	92	1.963787827
07/07/2020 10:18	ALERT_Sys_2	349	2.542825427
07/07/2020 10:07	LAB_1.1	197	2.294466226
07/07/2020 10:07	LAB_1.2	160	2.204119983
07/07/2020 10:17	LAB_2.1	253	2.403120521
07/07/2020 10:17	LAB_2.2	144	2.158362492
08/07/2020 10:30	ALERT_Lab_1.1	298	2.474216264
08/07/2020 10:30	ALERT_Lab_1.2	337	2.527629901
08/07/2020 10:40	ALERT_Lab_2.1	433	2.636487896
08/07/2020 10:40	ALERT_Lab_2.2	159	2.201397124
08/07/2020 10:40	ALERT_Lab_2.1_TC	212	2.326335861
08/07/2020 10:40	ALERT_Lab_2.2_TC	86	1.934498451
08/07/2020 12:42	ALERT_Sys_1	517	2.713490543
08/07/2020 12:45	ALERT_Sys_2	194	2.28780173
08/07/2020 12:47	ALERT_Sys_3	78	1.892094603
08/07/2020 10:30	LAB_1.1	249	2.396199347
08/07/2020 10:30	LAB_1.2	177	2.247973266
08/07/2020 10:40	LAB_2.1	144	2.158362492
08/07/2020 10:40	LAB_2.2	251	2.399673721
09/07/2020 11:52	ALERT_Lab_1.1	808	2.907411361

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09/07/2020 11:52	ALERT_Lab_1.2	794	2.899820502
09/07/2020 12:02	ALERT_Lab_2.1	983	2.992553518
09/07/2020 12:02	ALERT_Lab_2.2	220	2.342422681
09/07/2020 12:02	ALERT_Lab_2.1_TC	325	2.511883361
09/07/2020 12:02	ALERT_Lab_2.2_TC	418	2.621176282
09/07/2020 11:53	ALERT_Sys_1	1155	3.062581984
09/07/2020 12:03	ALERT_Sys_2	932	2.969415912
09/07/2020 15:12	ALERT_Sys_CSO_1	1804	3.256236533
09/07/2020 15:45	ALERT_Sys_CSO_2	536	2.72916479
09/07/2020 16:00	ALERT_Sys_CSO_3	508	2.705863712
09/07/2020 17:30	ALERT_Sys_CSO_4	36	1.556302501
09/07/2020 19:01	ALERT_Sys_CSO_5	159	2.201397124
09/07/2020 11:52	LAB_1.1	253	2.403120521
09/07/2020 11:52	LAB_1.2	232	2.365487985
09/07/2020 12:02	LAB_2.1	232	2.365487985
09/07/2020 12:02	LAB_2.2	327	2.514547753
10/07/2020 11:20	ALERT_Lab_1.1	1240	3.093421685
10/07/2020 11:20	ALERT_Lab_1.2	701	2.845718018
10/07/2020 11:30	ALERT_Lab_2.1	1405	3.147676324
10/07/2020 11:30	ALERT_Lab_2.2	576	2.760422483
10/07/2020 11:30	ALERT_Lab_2.1_TC	1482	3.170848204
10/07/2020 11:30	ALERT_Lab_2.2_TC	966	2.984977126
10/07/2020 11:21	ALERT_Sys_1	124	2.093421685
10/07/2020 11:30	ALERT_Sys_2	1134	3.054613055
10/07/2020 11:20	LAB_1.1	480	2.681241237
10/07/2020 11:20	LAB_1.2	419	2.622214023
10/07/2020 11:30	LAB_2.1	430	2.633468456
10/07/2020 11:30	LAB_2.2	368	2.565847819
13/07/2020 11:00	ALERT_Lab_1.1	375	2.574031268
13/07/2020 11:00	ALERT_Lab_1.2	337	2.527629901
13/07/2020 11:10	ALERT_Lab_2.1	212	2.326335861
13/07/2020 11:10	ALERT_Lab_2.2	208	2.318063335
13/07/2020 00:00	ALERT_Lab_2.1_TC		
13/07/2020 00:00	ALERT_Lab_2.2_TC		
13/07/2020 00:00	ALERT_Sys_1		
13/07/2020 00:00	ALERT_Sys_2		
13/07/2020 11:00	LAB_1.1	177	2.247973266
13/07/2020 11:00	LAB_1.2	330	2.51851394
13/07/2020 11:10	LAB_2.1	161	2.206825876
13/07/2020 11:10	LAB_2.2	234	2.369215857
14/07/2020 10:32	ALERT_Lab_1.1	129	2.11058971
14/07/2020 10:32	ALERT_Lab_1.2	127	2.103803721
14/07/2020 10:42	ALERT_Lab_2.1	240	2.380211242
14/07/2020 10:42	ALERT_Lab_2.2	106	2.025305865
14/07/2020 10:42	ALERT_Lab_2.1_TC	157	2.195899652
14/07/2020 10:42	ALERT_Lab_2.2_TC	154	2.187520721
14/07/2020 00:00	ALERT_Sys_1		
14/07/2020 00:00	ALERT_Sys_2		
14/07/2020 10:32	LAB_1.1	197	2.294466226

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14/07/2020 10:32	LAB_1.2	30	1.477121255
14/07/2020 10:42	LAB_2.1	213	2.328379603
14/07/2020 10:42	LAB_2.2	215	2.33243846
15/07/2020 00:00	ALERT_Lab_1.1		
15/07/2020 00:00	ALERT_Lab_1.2		
15/07/2020 00:00	ALERT_Lab_2.1		
15/07/2020 00:00	ALERT_Lab_2.2		
15/07/2020 11:20	ALERT_Lab_2.1_TC	228	2.357934847
15/07/2020 11:20	ALERT_Lab_2.2_TC	253	2.403120521
15/07/2020 12:19	ALERT_Sys_1	177	2.247973266
15/07/2020 12:20	ALERT_Sys_2	369	2.567026366
15/07/2020 00:00	LAB_1.1		
15/07/2020 00:00	LAB_1.2		
15/07/2020 00:00	LAB_2.1		
15/07/2020 00:00	LAB_2.2		
16/07/2020 10:06	ALERT_Lab_1.1	343	2.53529412
16/07/2020 10:06	ALERT_Lab_1.2	448	2.651278014
16/07/2020 10:16	ALERT_Lab_2.1	263	2.419955748
16/07/2020 10:16	ALERT_Lab_2.2	375	2.574031268
16/07/2020 10:16	ALERT_Lab_2.1_TC	298	2.474216264
16/07/2020 10:16	ALERT_Lab_2.2_TC	258	2.411619706
16/07/2020 10:05	ALERT_Sys_1	403	2.605305046
16/07/2020 10:15	ALERT_Sys_2	739	2.868644438
16/07/2020 10:06	LAB_1.1		
16/07/2020 10:06	LAB_1.2	253	2.403120521
16/07/2020 10:16	LAB_2.1	251	2.399673721
16/07/2020 10:16	LAB_2.2	142	2.152288344
17/07/2020 10:04	ALERT_Lab_1.1	184	2.264817823
17/07/2020 10:04	ALERT_Lab_1.2	154	2.187520721
17/07/2020 10:14	ALERT_Lab_2.1	151	2.178976947
17/07/2020 10:14	ALERT_Lab_2.2	174	2.240549248
17/07/2020 10:14	ALERT_Lab_2.1_TC	146	2.164352856
17/07/2020 10:14	ALERT_Lab_2.2_TC	143	2.155336037
17/07/2020 10:03	ALERT_Sys_1	473	2.674861141
17/07/2020 10:11	ALERT_Sys_2	106	2.025305865
17/07/2020 10:04	LAB_1.1		
17/07/2020 10:04	LAB_1.2	179	2.252853031
17/07/2020 10:14	LAB_2.1	144	2.158362492
17/07/2020 10:14	LAB_2.2	161	2.206825876
20/07/2020 00:00	ALERT_Lab_1.1		
20/07/2020 00:00	ALERT_Lab_1.2		
20/07/2020 00:00	ALERT_Lab_2.1		
20/07/2020 00:00	ALERT_Lab_2.2		
20/07/2020 12:11	ALERT_Lab_2.1_TC	44	1.643452676
20/07/2020 12:11	ALERT_Lab_2.2_TC	146	2.164352856
20/07/2020 00:00	ALERT_Sys_1		
20/07/2020 00:00	ALERT_Sys_2		
20/07/2020 12:01	LAB_1.1		
20/07/2020 12:01	LAB_1.2		

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20/07/2020 12:11	LAB_2.1		
20/07/2020 12:11	LAB_2.2		
21/07/2020 00:00	ALERT_Lab_1.1		
21/07/2020 00:00	ALERT_Lab_1.2		
21/07/2020 00:00	ALERT_Lab_2.1		
21/07/2020 00:00	ALERT_Lab_2.2		
21/07/2020 00:00	ALERT_Lab_2.1_TC		
21/07/2020 00:00	ALERT_Lab_2.2_TC		
21/07/2020 00:00	ALERT_Sys_1		
21/07/2020 00:00	ALERT_Sys_2		
21/07/2020 10:05	LAB_1.1	197	2.294466226
21/07/2020 10:05	LAB_1.2	161	2.206825876
21/07/2020 10:15	LAB_2.1	127	2.103803721
21/07/2020 10:15	LAB_2.2	177	2.247973266
22/07/2020 00:00	ALERT_Lab_1.1		
22/07/2020 00:00	ALERT_Lab_1.2		
22/07/2020 00:00	ALERT_Lab_2.1		
22/07/2020 00:00	ALERT_Lab_2.2		
22/07/2020 11:50	ALERT_Lab_2.1_TC	282	2.450249108
22/07/2020 11:50	ALERT_Lab_2.2_TC	205	2.311753861
22/07/2020 11:37	ALERT_Sys_1	12	1.079181246
22/07/2020 11:50	ALERT_Sys_2	108	2.033423755
22/07/2020 11:40	LAB_1.1		
22/07/2020 11:40	LAB_1.2		
22/07/2020 11:50	LAB_2.1		
22/07/2020 11:50	LAB_2.2		
23/07/2020 10:30	ALERT_Lab_1.1	410	2.612783857
23/07/2020 10:30	ALERT_Lab_1.2	546	2.737192643
23/07/2020 10:40	ALERT_Lab_2.1	536	2.72916479
23/07/2020 10:40	ALERT_Lab_2.2	282	2.450249108
23/07/2020 10:40	ALERT_Lab_2.1_TC	184	2.264817823
23/07/2020 10:40	ALERT_Lab_2.2_TC	208	2.318063335
23/07/2020 10:28	ALERT_Sys_1	83	1.919078092
23/07/2020 20:37	ALERT_Sys_2	165	2.217483944
23/07/2020 10:30	LAB_1.1	179	2.252853031
23/07/2020 10:30	LAB_1.2	161	2.206825876
23/07/2020 10:40	LAB_2.1	179	2.252853031
23/07/2020 10:40	LAB_2.2	126	2.100370545
24/07/2020 11:42	ALERT_Lab_1.1	143	2.155336037
24/07/2020 11:42	ALERT_Lab_1.2	212	2.326335861
24/07/2020 11:52	ALERT_Lab_2.1	396	2.597695186
24/07/2020 11:52	ALERT_Lab_2.2	263	2.419955748
24/07/2020 11:52	ALERT_Lab_2.1_TC	308	2.488550717
24/07/2020 11:52	ALERT_Lab_2.2_TC	508	2.705863712
24/07/2020 11:32	ALERT_Sys_1		
24/07/2020 11:44	ALERT_Sys_2		
24/07/2020 11:42	LAB_1.1	161	2.206825876
24/07/2020 11:42	LAB_1.2	127	2.103803721
24/07/2020 11:52	LAB_2.1	272	2.434568904

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24/07/2020 11:52	LAB_2.2	253	2.403120521
27/07/2020 10:28	ALERT_Lab_1.1	129	2.11058971
27/07/2020 10:28	ALERT_Lab_1.2	325	2.511883361
27/07/2020 10:38	ALERT_Lab_2.1	362	2.558708571
27/07/2020 10:38	ALERT_Lab_2.2	159	2.201397124
27/07/2020 10:38	ALERT_Lab_2.1_TC	282	2.450249108
27/07/2020 10:38	ALERT_Lab_2.2_TC	320	2.505149978
27/07/2020 10:28	ALERT_Sys_1	18	1.255272505
27/07/2020 10:38	ALERT_Sys_2		
27/07/2020 10:28	LAB_1.1	312	2.494154594
27/07/2020 10:28	LAB_1.2	195	2.290034611
27/07/2020 10:38	LAB_2.1	309	2.489958479
27/07/2020 10:38	LAB_2.2	312	2.494154594
28/07/2020 10:26	ALERT_Lab_1.1	356	2.551449998
28/07/2020 10:26	ALERT_Lab_1.2	349	2.542825427
28/07/2020 10:36	ALERT_Lab_2.1	396	2.597695186
28/07/2020 10:36	ALERT_Lab_2.2	118	2.071882007
28/07/2020 10:36	ALERT_Lab_2.1_TC	389	2.589949601
28/07/2020 10:36	ALERT_Lab_2.2_TC	216	2.334453751
28/07/2020 10:26	ALERT_Sys_1	253	2.403120521
28/07/2020 10:36	ALERT_Sys_2	18	1.255272505
28/07/2020 10:26	LAB_1.1	268	2.428134794
28/07/2020 10:26	LAB_1.2	127	2.103803721
28/07/2020 10:36	LAB_2.1	197	2.294466226
28/07/2020 10:36	LAB_2.2	347	2.540329475
29/07/2020 11:53	ALERT_Lab_1.1	433	2.636487896
29/07/2020 11:53	ALERT_Lab_1.2	425	2.62838893
29/07/2020 12:03	ALERT_Lab_2.1	343	2.53529412
29/07/2020 12:03	ALERT_Lab_2.2	141	2.149219113
29/07/2020 12:03	ALERT_Lab_2.1_TC	308	2.488550717
29/07/2020 12:03	ALERT_Lab_2.2_TC	157	2.195899652
29/07/2020 11:54	ALERT_Sys_1	356	2.551449998
29/07/2020 12:02	ALERT_Sys_2	69	1.838849091
29/07/2020 11:53	LAB_1.1	177	2.247973266
29/07/2020 11:53	LAB_1.2	94	1.973127854
29/07/2020 12:03	LAB_2.1	127	2.103803721
29/07/2020 12:03	LAB_2.2	712	2.852479994
30/07/2020 10:11	ALERT_Lab_1.1	100	2
30/07/2020 10:11	ALERT_Lab_1.2	177	2.247973266
30/07/2020 10:21	ALERT_Lab_2.1	389	2.589949601
30/07/2020 10:21	ALERT_Lab_2.2	106	2.025305865
30/07/2020 10:21	ALERT_Lab_2.1_TC	127	2.103803721
30/07/2020 10:21	ALERT_Lab_2.2_TC	136	2.133538908
30/07/2020 10:11	ALERT_Sys_1	33	1.51851394
30/07/2020 10:21	ALERT_Sys_2		
30/07/2020 10:11	LAB_1.1	144	2.158362492
30/07/2020 10:11	LAB_1.2	127	2.103803721
30/07/2020 10:21	LAB_2.1	94	1.973127854
30/07/2020 10:21	LAB_2.2	126	2.100370545

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31/07/2020 10:00	ALERT_Lab_1.1	205	2.311753861
31/07/2020 10:00	ALERT_Lab_1.2	236	2.372912003
31/07/2020 10:10	ALERT_Lab_2.1	253	2.403120521
31/07/2020 10:10	ALERT_Lab_2.2	122	2.086359831
31/07/2020 00:00	ALERT_Lab_2.1_TC		
31/07/2020 00:00	ALERT_Lab_2.2_TC		
31/07/2020 10:00	ALERT_Sys_1	739	2.868644438
31/07/2020 10:11	ALERT_Sys_2	403	2.605305046
31/07/2020 10:00	LAB_1.1	126	2.100370545
31/07/2020 10:00	LAB_1.2	195	2.290034611
31/07/2020 10:10	LAB_2.1	110	2.041392685
31/07/2020 10:10	LAB_2.2	127	2.103803721
03/08/2020 12:27	ALERT_Lab_1.1	369	2.567026366
03/08/2020 12:27	ALERT_Lab_1.2	303	2.481442629
03/08/2020 12:37	ALERT_Lab_2.1	425	2.62838893
03/08/2020 12:37	ALERT_Lab_2.2	171	2.23299611
03/08/2020 12:37	ALERT_Lab_2.1_TC	162	2.209515015
03/08/2020 12:37	ALERT_Lab_2.2_TC	362	2.558708571
03/08/2020 12:28	ALERT_Sys_1		
03/08/2020 12:37	ALERT_Sys_2	220	2.342422681
03/08/2020 12:27	LAB_1.1	176	2.245512668
03/08/2020 12:27	LAB_1.2	109	2.037426498
03/08/2020 12:37	LAB_2.1	94	1.973127854
03/08/2020 12:37	LAB_2.2	144	2.158362492
04/08/2020 10:03	ALERT_Lab_1.1	441	2.644438589
04/08/2020 10:03	ALERT_Lab_1.2	433	2.636487896
04/08/2020 10:13	ALERT_Lab_2.1	546	2.737192643
04/08/2020 10:13	ALERT_Lab_2.2	162	2.209515015
04/08/2020 10:13	ALERT_Lab_2.1_TC	375	2.574031268
04/08/2020 10:13	ALERT_Lab_2.2_TC	174	2.240549248
04/08/2020 10:03	ALERT_Sys_1	24	1.380211242
04/08/2020 10:12	ALERT_Sys_2	50	1.698970004
04/08/2020 10:03	LAB_1.1	232	2.365487985
04/08/2020 10:03	LAB_1.2	142	2.152288344
04/08/2020 10:13	LAB_2.1	144	2.158362492
04/08/2020 10:13	LAB_2.2	179	2.252853031
05/08/2020 10:33	ALERT_Lab_1.1	171	2.23299611
05/08/2020 10:33	ALERT_Lab_1.2	482	2.683047038
05/08/2020 10:49	ALERT_Lab_2.1	187	2.271841607
05/08/2020 10:49	ALERT_Lab_2.2	433	2.636487896
05/08/2020 10:49	ALERT_Lab_2.1_TC		
05/08/2020 10:49	ALERT_Lab_2.2_TC		
05/08/2020 10:48	ALERT_Sys_1	303	2.481442629
05/08/2020 10:50	ALERT_Sys_2		
05/08/2020 10:33	LAB_1.1	270	2.431363764
05/08/2020 10:33	LAB_1.2	215	2.33243846
05/08/2020 10:49	LAB_2.1	144	2.158362492
05/08/2020 10:49	LAB_2.2	212	2.326335861
06/08/2020 11:53	ALERT_Lab_1.1	490	2.69019608

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06/08/2020 11:53	ALERT_Lab_1.2	208	2.318063335
06/08/2020 12:03	ALERT_Lab_2.1	120	2.079181246
06/08/2020 12:03	ALERT_Lab_2.2	133	2.123851641
06/08/2020 12:03	ALERT_Lab_2.1_TC	94	1.973127854
06/08/2020 12:03	ALERT_Lab_2.2_TC	171	2.23299611
06/08/2020 11:53	ALERT_Sys_1	90	1.954242509
06/08/2020 12:02	ALERT_Sys_2	21	1.322219295
06/08/2020 11:53	LAB_1.1	195	2.290034611
06/08/2020 11:53	LAB_1.2	109	2.037426498
06/08/2020 12:03	LAB_2.1	197	2.294466226
06/08/2020 12:03	LAB_2.2	77	1.886490725
07/08/2020 10:05	ALERT_Lab_1.1	546	2.737192643
07/08/2020 10:05	ALERT_Lab_1.2	228	2.357934847
07/08/2020 10:15	ALERT_Lab_2.1	181	2.257678575
07/08/2020 10:15	ALERT_Lab_2.2	151	2.178976947
07/08/2020 10:15	ALERT_Lab_2.1_TC	228	2.357934847
07/08/2020 10:15	ALERT_Lab_2.2_TC	258	2.411619706
07/08/2020 10:05	ALERT_Sys_1	194	2.28780173
07/08/2020 10:14	ALERT_Sys_2	51	1.707570176
07/08/2020 10:05	LAB_1.1	195	2.290034611
07/08/2020 10:05	LAB_1.2	127	2.103803721
07/08/2020 10:15	LAB_2.1	232	2.365487985
07/08/2020 10:15	LAB_2.2	94	1.973127854
10/08/2020 10:10	ALERT_Lab_1.1	141	2.149219113
10/08/2020 10:10	ALERT_Lab_1.2	181	2.257678575
10/08/2020 10:20	ALERT_Lab_2.1	110	2.041392685
10/08/2020 10:20	ALERT_Lab_2.2	84	1.924279286
10/08/2020 10:20	ALERT_Lab_2.1_TC	232	2.365487985
10/08/2020 10:20	ALERT_Lab_2.2_TC	138	2.139879086
10/08/2020 10:10	ALERT_Sys_1	303	2.481442629
10/08/2020 10:18	ALERT_Sys_2	18	1.255272505
10/08/2020 10:10	LAB_1.1	46	1.662757832
10/08/2020 10:10	LAB_1.2	126	2.100370545
10/08/2020 10:20	LAB_2.1	77	1.886490725
10/08/2020 10:20	LAB_2.2	77	1.886490725
11/08/2020 00:00	ALERT_Lab_1.1		
11/08/2020 00:00	ALERT_Lab_1.2		
11/08/2020 00:00	ALERT_Lab_2.1		
11/08/2020 00:00	ALERT_Lab_2.2		
11/08/2020 11:32	ALERT_Lab_2.1_TC	249	2.396199347
11/08/2020 11:32	ALERT_Lab_2.2_TC	441	2.644438589
11/08/2020 11:22	ALERT_Sys_1	465	2.667452953
11/08/2020 11:32	ALERT_Sys_2	258	2.411619706
11/08/2020 11:22	LAB_1.1	197	2.294466226
11/08/2020 11:22	LAB_1.2	176	2.245512668
11/08/2020 11:32	LAB_2.1	177	2.247973266
11/08/2020 11:32	LAB_2.2	161	2.206825876
12/08/2020 00:00	ALERT_Lab_1.1		
12/08/2020 00:00	ALERT_Lab_1.2		

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12/08/2020 00:00	ALERT_Lab_2.1		
12/08/2020 00:00	ALERT_Lab_2.2		
12/08/2020 10:24	ALERT_Lab_2.1_TC	499	2.698100546
12/08/2020 10:24	ALERT_Lab_2.2_TC	154	2.187520721
12/08/2020 10:15	ALERT_Sys_1	59	1.770852012
12/08/2020 10:24	ALERT_Sys_2	80	1.903089987
12/08/2020 10:24	LAB_1.1		
12/08/2020 10:24	LAB_1.2		
12/08/2020 10:24	LAB_2.1		
12/08/2020 10:24	LAB_2.2		
13/08/2020 00:00	ALERT_Lab_1.1		
13/08/2020 00:00	ALERT_Lab_1.2		
13/08/2020 00:00	ALERT_Lab_2.1		
13/08/2020 00:00	ALERT_Lab_2.2		
13/08/2020 00:00	ALERT_Lab_2.1_TC		
13/08/2020 00:00	ALERT_Lab_2.2_TC		
13/08/2020 10:06	ALERT_Sys_1	258	2.411619706
13/08/2020 10:16	ALERT_Sys_2	80	1.903089987
13/08/2020 10:06	LAB_1.1		
13/08/2020 10:06	LAB_1.2		
13/08/2020 10:16	LAB_2.1		
13/08/2020 10:16	LAB_2.2		
14/08/2020 00:00	ALERT_Lab_1.1		
14/08/2020 00:00	ALERT_Lab_1.2		
14/08/2020 00:00	ALERT_Lab_2.1		
14/08/2020 00:00	ALERT_Lab_2.2		
14/08/2020 00:00	ALERT_Lab_2.1_TC		
14/08/2020 00:00	ALERT_Lab_2.2_TC		
14/08/2020 00:00	ALERT_Sys_1		
14/08/2020 11:28	ALERT_Sys_2	51	1.707570176
14/08/2020 11:18	LAB_1.1		
14/08/2020 11:18	LAB_1.2		
14/08/2020 11:28	LAB_2.1		
14/08/2020 11:28	LAB_2.2		
17/08/2020 00:00	ALERT_Lab_1.1		
17/08/2020 00:00	ALERT_Lab_1.2		
17/08/2020 00:00	ALERT_Lab_2.1		
17/08/2020 00:00	ALERT_Lab_2.2		
17/08/2020 00:00	ALERT_Lab_2.1_TC		
17/08/2020 00:00	ALERT_Lab_2.2_TC		
17/08/2020 10:05	ALERT_Sys_1	165	2.217483944
17/08/2020 10:15	ALERT_Sys_2	33	1.51851394
17/08/2020 10:05	LAB_1.1		
17/08/2020 10:05	LAB_1.2		
17/08/2020 10:15	LAB_2.1		
17/08/2020 10:15	LAB_2.2		
18/08/2020 00:00	ALERT_Lab_1.1		
18/08/2020 00:00	ALERT_Lab_1.2		
18/08/2020 00:00	ALERT_Lab_2.1		

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18/08/2020 00:00	ALERT_Lab_2.2		
18/08/2020 00:00	ALERT_Lab_2.1_TC		
18/08/2020 00:00	ALERT_Lab_2.2_TC		
18/08/2020 10:14	ALERT_Sys_1	168	2.225309282
18/08/2020 10:25	ALERT_Sys_2	9	0.954242509
18/08/2020 10:15	LAB_1.1		
18/08/2020 10:15	LAB_1.2		
18/08/2020 10:25	LAB_2.1		
18/08/2020 10:25	LAB_2.2		
19/08/2020 00:00	ALERT_Lab_1.1		
19/08/2020 00:00	ALERT_Lab_1.2		
19/08/2020 00:00	ALERT_Lab_2.1		
19/08/2020 00:00	ALERT_Lab_2.2		
19/08/2020 00:00	ALERT_Lab_2.1_TC		
19/08/2020 00:00	ALERT_Lab_2.2_TC		
19/08/2020 11:35	ALERT_Sys_1	739	2.868644438
19/08/2020 11:45	ALERT_Sys_2	303	2.481442629
19/08/2020 11:35	LAB_1.1		
19/08/2020 11:35	LAB_1.2		
19/08/2020 11:45	LAB_2.1		
19/08/2020 11:45	LAB_2.2		
20/08/2020 00:00	ALERT_Lab_1.1		
20/08/2020 00:00	ALERT_Lab_1.2		
20/08/2020 00:00	ALERT_Lab_2.1		
20/08/2020 00:00	ALERT_Lab_2.2		
20/08/2020 00:00	ALERT_Lab_2.1_TC		
20/08/2020 00:00	ALERT_Lab_2.2_TC		
20/08/2020 10:05	ALERT_Sys_1	739	2.868644438
20/08/2020 10:14	ALERT_Sys_2	1536	3.186391216
20/08/2020 10:04	LAB_1.1		
20/08/2020 10:04	LAB_1.2		
20/08/2020 10:14	LAB_2.1		
20/08/2020 10:14	LAB_2.2		
21/08/2020 00:00	ALERT_Lab_1.1		
21/08/2020 00:00	ALERT_Lab_1.2		
21/08/2020 00:00	ALERT_Lab_2.1		
21/08/2020 00:00	ALERT_Lab_2.2		
21/08/2020 00:00	ALERT_Lab_2.1_TC		
21/08/2020 00:00	ALERT_Lab_2.2_TC		
21/08/2020 10:02	ALERT_Sys_1	473	2.674861141
21/08/2020 10:13	ALERT_Sys_2	92	1.963787827
21/08/2020 10:02	LAB_1.1		
21/08/2020 10:02	LAB_1.2		
21/08/2020 10:12	LAB_2.1		
21/08/2020 10:12	LAB_2.2		
24/08/2020 10:09	ALERT_Lab_1.1	433	2.636487896
24/08/2020 10:09	ALERT_Lab_1.2	224	2.350248018
24/08/2020 10:19	ALERT_Lab_2.1	187	2.271841607
24/08/2020 10:19	ALERT_Lab_2.2	208	2.318063335

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24/08/2020 10:19	ALERT_Lab_2.1_TC	184	2.264817823
24/08/2020 10:19	ALERT_Lab_2.2_TC	181	2.257678575
24/08/2020 10:10	ALERT_Sys_1	303	2.481442629
24/08/2020 00:00	ALERT_Sys_2		
24/08/2020 10:09	LAB_1.1		
24/08/2020 10:09	LAB_1.2		
24/08/2020 10:19	LAB_2.1		
24/08/2020 10:19	LAB_2.2		
25/08/2020 11:59	ALERT_Lab_1.1	197	2.294466226
25/08/2020 11:59	ALERT_Lab_1.2	245	2.389166084
25/08/2020 12:09	ALERT_Lab_2.1	216	2.334453751
25/08/2020 12:09	ALERT_Lab_2.2	208	2.318063335
25/08/2020 12:09	ALERT_Lab_2.1_TC	325	2.511883361
25/08/2020 12:09	ALERT_Lab_2.2_TC	282	2.450249108
25/08/2020 12:00	ALERT_Sys_1	122	2.086359831
25/08/2020 12:09	ALERT_Sys_2	356	2.551449998
25/08/2020 11:59	LAB_1.1		
25/08/2020 11:59	LAB_1.2		
25/08/2020 12:09	LAB_2.1		
25/08/2020 12:09	LAB_2.2		
26/08/2020 10:15	ALERT_Lab_1.1	490	2.69019608
26/08/2020 10:15	ALERT_Lab_1.2	1001	3.000434077
26/08/2020 10:25	ALERT_Lab_2.1	664	2.822168079
26/08/2020 10:25	ALERT_Lab_2.2	490	2.69019608
26/08/2020 10:25	ALERT_Lab_2.1_TC	664	2.822168079
26/08/2020 10:25	ALERT_Lab_2.2_TC	331	2.519827994
26/08/2020 10:15	ALERT_Sys_1	44	1.643452676
26/08/2020 10:25	ALERT_Sys_2	1155	3.062581984
26/08/2020 10:15	LAB_1.1		
26/08/2020 10:15	LAB_1.2	375	2.574031268
26/08/2020 10:25	LAB_2.1	486	2.686636269
26/08/2020 10:25	LAB_2.2	415	2.618048097
27/08/2020 11:51	ALERT_Lab_1.1	4405	3.643945913
27/08/2020 11:51	ALERT_Lab_1.2	4566	3.659535907
27/08/2020 12:02	ALERT_Lab_2.1	3028	3.481155871
27/08/2020 12:02	ALERT_Lab_2.2	3819	3.581949658
27/08/2020 12:02	ALERT_Lab_2.1_TC	3620	3.558708571
27/08/2020 12:02	ALERT_Lab_2.2_TC	2974	3.473340964
27/08/2020 11:51	ALERT_Sys_1	6884	3.837840862
27/08/2020 12:03	ALERT_Sys_2	5968	3.775828814
27/08/2020 11:51	LAB_1.1	3672	3.564902673
27/08/2020 11:51	LAB_1.2	5350	3.728353782
27/08/2020 12:02	LAB_2.1	3719	3.570426178
27/08/2020 12:02	LAB_2.2	3197	3.504742636
28/08/2020 11:26	ALERT_Lab_1.1	499	2.698100546
28/08/2020 11:26	ALERT_Lab_1.2	258	2.411619706
28/08/2020 11:36	ALERT_Lab_2.1	308	2.488550717
28/08/2020 11:36	ALERT_Lab_2.2	232	2.365487985
28/08/2020 11:36	ALERT_Lab_2.1_TC	177	2.247973266

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28/08/2020 11:36	ALERT_Lab_2.2_TC	120	2.079181246
28/08/2020 11:28	ALERT_Sys_1	482	2.683047038
28/08/2020 11:37	ALERT_Sys_2	565	2.752048448
28/08/2020 11:26	LAB_1.1	192	2.283301229
28/08/2020 11:26	LAB_1.2	289	2.460897843
28/08/2020 11:36	LAB_2.1	234	2.369215857
28/08/2020 11:36	LAB_2.2	110	2.041392685
30/08/2020 20:09	ALERT_Sys_CSO_1		
30/08/2020 20:11	ALERT_Sys_CSO_2	1001	3.000434077
31/08/2020 10:17	ALERT_Lab_1.1	899	2.953759692
31/08/2020 10:17	ALERT_Lab_1.2	586	2.767897616
31/08/2020 10:28	ALERT_Lab_2.1	396	2.597695186
31/08/2020 10:28	ALERT_Lab_2.2	389	2.589949601
31/08/2020 10:28	ALERT_Lab_2.1_TC	576	2.760422483
31/08/2020 10:28	ALERT_Lab_2.2_TC	331	2.519827994
31/08/2020 10:16	ALERT_Sys_1	629	2.798650645
31/08/2020 10:29	ALERT_Sys_2	228	2.357934847
31/08/2020 10:17	LAB_1.1	312	2.494154594
31/08/2020 10:17	LAB_1.2	372	2.57054294
31/08/2020 10:28	LAB_2.1	327	2.514547753
31/08/2020 10:28	LAB_2.2	195	2.290034611
01/09/2020 12:06	ALERT_Lab_1.1	837	2.922725458
01/09/2020 12:06	ALERT_Lab_1.2	410	2.612783857
01/09/2020 12:16	ALERT_Lab_2.1	546	2.737192643
01/09/2020 12:16	ALERT_Lab_2.2	701	2.845718018
01/09/2020 12:16	ALERT_Lab_2.1_TC	267	2.426511261
01/09/2020 12:16	ALERT_Lab_2.2_TC	837	2.922725458
01/09/2020 12:07	ALERT_Sys_1	473	2.674861141
01/09/2020 12:15	ALERT_Sys_2	983	2.992553518
01/09/2020 12:06	LAB_1.1	179	2.252853031
01/09/2020 12:06	LAB_1.2	272	2.434568904
01/09/2020 12:16	LAB_2.1	195	2.290034611
01/09/2020 12:16	LAB_2.2	215	2.33243846
02/09/2020 10:21	ALERT_Lab_1.1	236	2.372912003
02/09/2020 10:21	ALERT_Lab_1.2	320	2.505149978
02/09/2020 10:31	ALERT_Lab_2.1	174	2.240549248
02/09/2020 10:31	ALERT_Lab_2.2	546	2.737192643
02/09/2020 10:31	ALERT_Lab_2.1_TC	165	2.217483944
02/09/2020 10:31	ALERT_Lab_2.2_TC	191	2.281033367
02/09/2020 10:20	ALERT_Sys_1	536	2.72916479
02/09/2020 10:30	ALERT_Sys_2	224	2.350248018
02/09/2020 10:21	LAB_1.1	127	2.103803721
02/09/2020 10:21	LAB_1.2	94	1.973127854
02/09/2020 10:31	LAB_2.1	144	2.158362492
02/09/2020 10:31	LAB_2.2	127	2.103803721
03/09/2020 10:26	ALERT_Lab_1.1	6185	3.791339704
03/09/2020 10:26	ALERT_Lab_1.2	4327	3.636186895
03/09/2020 10:36	ALERT_Lab_2.1	5657	3.752586179
03/09/2020 10:36	ALERT_Lab_2.2	5556	3.744762237

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03/09/2020 10:36	ALERT_Lab_2.1_TC	4327	3.636186895
03/09/2020 10:36	ALERT_Lab_2.2_TC	5173	3.713742478
03/09/2020 10:27	ALERT_Sys_1	5968	3.775828814
03/09/2020 10:38	ALERT_Sys_2	4405	3.643945913
03/09/2020 10:26	LAB_1.1	4103	3.613101517
03/09/2020 10:26	LAB_1.2	6581	3.818291891
03/09/2020 10:36	LAB_2.1	4500	3.653212514
03/09/2020 10:36	LAB_2.2	7100	3.851258349
04/09/2020 13:00	ALERT_Lab_1.1	794	2.899820502
04/09/2020 13:00	ALERT_Lab_1.2	868	2.938519725
04/09/2020 13:10	ALERT_Lab_2.1	641	2.80685803
04/09/2020 13:10	ALERT_Lab_2.2	966	2.984977126
04/09/2020 13:10	ALERT_Lab_2.1_TC	465	2.667452953
04/09/2020 13:10	ALERT_Lab_2.2_TC	852	2.930439595
04/09/2020 13:00	ALERT_Sys_1	641	2.80685803
04/09/2020 13:10	ALERT_Sys_2	983	2.992553518
04/09/2020 13:00	LAB_1.1	514	2.710963119
04/09/2020 13:00	LAB_1.2	499	2.698100546
04/09/2020 13:10	LAB_2.1	580	2.763427994
04/09/2020 13:10	LAB_2.2		
07/09/2020 10:08	ALERT_Lab_1.1	555	2.744292983
07/09/2020 10:08	ALERT_Lab_1.2	517	2.713490543
07/09/2020 10:18	ALERT_Lab_2.1	517	2.713490543
07/09/2020 10:18	ALERT_Lab_2.2	586	2.767897616
07/09/2020 10:18	ALERT_Lab_2.1_TC	201	2.303196057
07/09/2020 10:18	ALERT_Lab_2.2_TC	433	2.636487896
07/09/2020 10:07	ALERT_Sys_1	263	2.419955748
07/09/2020 10:17	ALERT_Sys_2	343	2.53529412
07/09/2020 10:08	LAB_1.1	270	2.431363764
07/09/2020 10:08	LAB_1.2	215	2.33243846
07/09/2020 10:18	LAB_2.1	176	2.245512668
07/09/2020 10:18	LAB_2.2	353	2.547774705
08/09/2020 10:15	ALERT_Lab_1.1	536	2.72916479
08/09/2020 10:15	ALERT_Lab_1.2	457	2.6599162
08/09/2020 10:25	ALERT_Lab_2.1	308	2.488550717
08/09/2020 10:25	ALERT_Lab_2.2	739	2.868644438
08/09/2020 10:25	ALERT_Lab_2.1_TC	314	2.496929648
08/09/2020 10:25	ALERT_Lab_2.2_TC	576	2.760422483
08/09/2020 10:16	ALERT_Sys_1	1155	3.062581984
08/09/2020 10:24	ALERT_Sys_2		
08/09/2020 10:15	LAB_1.1	750	2.875061263
08/09/2020 10:15	LAB_1.2	538	2.730782276
08/09/2020 10:25	LAB_2.1	509	2.706717782
08/09/2020 10:25	LAB_2.2	529	2.723455672
09/09/2020 11:40	ALERT_Lab_1.1	2769	3.442322956
09/09/2020 11:40	ALERT_Lab_1.2	410	2.612783857
09/09/2020 11:50	ALERT_Lab_2.1	1482	3.170848204
09/09/2020 11:50	ALERT_Lab_2.2	3311	3.519959181
09/09/2020 11:50	ALERT_Lab_2.1_TC	418	2.621176282

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09/09/2020 11:50	ALERT_Lab_2.2_TC	2358	3.372543801
09/09/2020 00:00	ALERT_Sys_1		
09/09/2020 00:00	ALERT_Sys_2		
09/09/2020 11:40	LAB_1.1	9050	3.956648579
09/09/2020 11:40	LAB_1.2	5350	3.728353782
09/09/2020 11:50	LAB_2.1	4075	3.610127613
09/09/2020 11:50	LAB_2.2	5350	3.728353782
10/09/2020 10:15	ALERT_Lab_1.1	382	2.582063363
10/09/2020 10:15	ALERT_Lab_1.2	249	2.396199347
10/09/2020 10:25	ALERT_Lab_2.1	433	2.636487896
10/09/2020 10:25	ALERT_Lab_2.2	325	2.511883361
10/09/2020 10:25	ALERT_Lab_2.1_TC	165	2.217483944
10/09/2020 10:25	ALERT_Lab_2.2_TC	282	2.450249108
10/09/2020 00:00	ALERT_Sys_1		
10/09/2020 00:00	ALERT_Sys_2		
10/09/2020 10:15	LAB_1.1	161	2.206825876
10/09/2020 10:15	LAB_1.2	289	2.460897843
10/09/2020 10:25	LAB_2.1	330	2.51851394
10/09/2020 10:25	LAB_2.2	266	2.424881637
08/08/2019 08:31	ALERT_Sys_1	1804	3.256236533
08/08/2019 09:00	ALERT_Sys_2	1564	3.194236749
08/08/2019 17:00	ALERT_Sys_3	1564	3.194236749
09/08/2019 11:13	ALERT_Sys_1	1001	3.000434077
09/08/2019 11:45	ALERT_Sys_2	473	2.674861141
10/08/2019 09:00	no_sample		
10/08/2019 17:01	ALERT_Sys_1	1804	3.256236533
11/08/2019 09:00	ALERT_Sys_1	1804	3.256236533
11/08/2019 17:00	ALERT_Sys_2	868	2.938519725
12/08/2019 13:29	ALERT_Sys_1	263	2.419955748
12/08/2019 14:30	ALERT_Sys_2	1001	3.000434077
13/08/2019 09:10	ALERT_Sys_1	852	2.930439595
13/08/2019 10:15	ALERT_Sys_2	303	2.481442629
13/08/2019 17:00	ALERT_Sys_3	410	2.612783857
14/08/2019 12:20	ALERT_Sys_1	739	2.868644438
14/08/2019 12:34	ALERT_Sys_2	473	2.674861141
14/08/2019 17:00	ALERT_Sys_3	349	2.542825427
15/08/2019 09:23	ALERT_Sys_1	356	2.551449998
15/08/2019 10:12	ALERT_Sys_2	1804	3.256236533
15/08/2019 17:00	ALERT_Sys_3	739	2.868644438
16/08/2019 11:02	ALERT_Sys_1	168	2.225309282
16/08/2019 11:39	ALERT_Sys_2	641	2.80685803
16/08/2019 17:00	ALERT_Sys_3	124	2.093421685
17/08/2019 09:00	ALERT_Sys_1	194	2.28780173
17/08/2019 17:01	ALERT_Sys_2	868	2.938519725
18/08/2019 09:00	ALERT_Sys_1	1155	3.062581984
18/08/2019 17:00	ALERT_Sys_2	555	2.744292983
19/08/2019 11:11	ALERT_Sys_1	2444	3.388101202
19/08/2019 11:19	ALERT_Sys_2	3819	3.581949658
19/08/2019 13:57	ALERT_Sys_3	3819	3.581949658

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19/08/2019 15:00	ALERT_Sys_4	555	2.744292983
19/08/2019 17:00	ALERT_Sys_5	403	2.605305046
19/08/2019 18:01	ALERT_Sys_6	868	2.938519725
19/08/2019 19:01	ALERT_Sys_7	303	2.481442629
20/08/2019 11:23	ALERT_Sys_1	739	2.868644438
20/08/2019 11:29	ALERT_Sys_2	2444	3.388101202
20/08/2019 13:03	ALERT_Sys_3	1155	3.062581984
20/08/2019 14:30	ALERT_Sys_4	739	2.868644438
20/08/2019 16:00	ALERT_Sys_5	473	2.674861141
20/08/2019 17:31	ALERT_Sys_6	739	2.868644438
20/08/2019 19:00	ALERT_Sys_7	868	2.938519725
21/08/2019 11:11	ALERT_Sys_1	410	2.612783857
21/08/2019 11:24	ALERT_Sys_2	1155	3.062581984
21/08/2019 12:58	ALERT_Sys_3	168	2.225309282
21/08/2019 14:28	ALERT_Sys_4	124	2.093421685
21/08/2019 16:00	ALERT_Sys_5	3311	3.519959181
21/08/2019 17:30	ALERT_Sys_6	852	2.930439595
21/08/2019 19:00	ALERT_Sys_7	258	2.411619706
22/08/2019 11:20	ALERT_Sys_1	194	2.28780173
22/08/2019 11:28	ALERT_Sys_2	1001	3.000434077
22/08/2019 13:00	ALERT_Sys_3	403	2.605305046
22/08/2019 14:30	ALERT_Sys_4	629	2.798650645
22/08/2019 16:27	ALERT_Sys_5	303	2.481442629
22/08/2019 17:31	ALERT_Sys_6	228	2.357934847
22/08/2019 19:01	ALERT_Sys_7	194	2.28780173
23/08/2019 11:03	ALERT_Sys_1	555	2.744292983
23/08/2019 11:13	ALERT_Sys_2	124	2.093421685
23/08/2019 19:00	ALERT_Sys_3	263	2.419955748
24/08/2019 09:00	ALERT_Sys_1	124	2.093421685
24/08/2019 17:01	ALERT_Sys_2	555	2.744292983
25/08/2019 09:00	ALERT_Sys_1	555	2.744292983
25/08/2019 17:01	ALERT_Sys_2	555	2.744292983
26/08/2019 10:40	no_sample		
26/08/2019 10:49	ALERT_Sys_1	410	2.612783857
26/08/2019 12:59	ALERT_Sys_2	303	2.481442629
26/08/2019 14:31	ALERT_Sys_3	191	2.281033367
26/08/2019 16:00	ALERT_Sys_4	263	2.419955748
26/08/2019 17:30	ALERT_Sys_5	629	2.798650645
26/08/2019 19:00	ALERT_Sys_6	403	2.605305046
27/08/2019 12:51	ALERT_Sys_1	122	2.086359831
27/08/2019 13:13	ALERT_Sys_2	473	2.674861141
27/08/2019 15:17	ALERT_Sys_3	146	2.164352856
27/08/2019 16:00	ALERT_Sys_4	108	2.033423755
27/08/2019 17:00	ALERT_Sys_5	546	2.737192643
27/08/2019 18:00	ALERT_Sys_6	403	2.605305046
27/08/2019 19:01	ALERT_Sys_7	2081	3.31827208
28/08/2019 10:47	no_sample		
28/08/2019 10:50	ALERT_Sys_1	868	2.938519725
28/08/2019 11:01	ALERT_Sys_2	1001	3.000434077

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28/08/2019 17:01	ALERT_Sys_3	108	2.033423755
29/08/2019 09:00	ALERT_Sys_1	739	2.868644438
29/08/2019 13:00	ALERT_Sys_2	1155	3.062581984
29/08/2019 17:00	ALERT_Sys_3	473	2.674861141
30/08/2019 11:02	ALERT_Sys_1	410	2.612783857
30/08/2019 11:11	ALERT_Sys_2	94	1.973127854
31/08/2019 09:00	ALERT_Sys_1	168	2.225309282
31/08/2019 17:30	ALERT_Sys_2	555	2.744292983
01/09/2019 09:00	ALERT_Sys_1	1564	3.194236749
01/09/2019 17:30	ALERT_Sys_2	868	2.938519725
01/09/2019 19:01	ALERT_Sys_3	94	1.973127854
02/09/2019 11:35	ALERT_Sys_1	465	2.667452953
02/09/2019 12:03	ALERT_Sys_2	868	2.938519725
02/09/2019 13:00	ALERT_Sys_3	473	2.674861141
02/09/2019 14:30	ALERT_Sys_4	124	2.093421685
02/09/2019 16:06	ALERT_Sys_5	473	2.674861141
02/09/2019 17:30	ALERT_Sys_6	629	2.798650645
02/09/2019 19:01	ALERT_Sys_7	473	2.674861141
03/09/2019 12:09	ALERT_Sys_1	555	2.744292983
03/09/2019 12:17	ALERT_Sys_2	555	2.744292983
03/09/2019 14:28	ALERT_Sys_3	124	2.093421685
03/09/2019 16:00	no_sample		
03/09/2019 17:30	ALERT_Sys_4	726	2.860936621
03/09/2019 19:00	ALERT_Sys_5	349	2.542825427
04/09/2019 11:26	ALERT_Sys_1	349	2.542825427
04/09/2019 11:47	ALERT_Sys_2	1356	3.13225969
04/09/2019 12:59	ALERT_Sys_3	303	2.481442629
04/09/2019 14:29	ALERT_Sys_4	641	2.80685803
04/09/2019 17:30	ALERT_Sys_5	641	2.80685803
04/09/2019 19:00	ALERT_Sys_6	641	2.80685803
05/09/2019 11:09	no_sample		
05/09/2019 11:49	ALERT_Sys_1	2819	3.450095076
05/09/2019 12:03	ALERT_Sys_2	1804	3.256236533
05/09/2019 12:48	ALERT_Sys_4	2119	3.326130957
05/09/2019 12:50	ALERT_Sys_5	1001	3.000434077
06/09/2019 10:43	ALERT_Sys_1	124	2.093421685
06/09/2019 10:59	ALERT_Sys_2	228	2.357934847
06/09/2019 17:30	ALERT_Sys_3	39	1.591064607
07/09/2019 09:00	ALERT_Sys_1	473	2.674861141
07/09/2019 17:31	ALERT_Sys_2	263	2.419955748
08/09/2019 09:00	ALERT_Sys_1	473	2.674861141
08/09/2019 17:30	ALERT_Sys_2	868	2.938519725
09/09/2019 12:46	ALERT_Sys_1	739	2.868644438
09/09/2019 12:59	ALERT_Sys_2	1356	3.13225969
09/09/2019 14:29	ALERT_Sys_3	1564	3.194236749
09/09/2019 17:30	ALERT_Sys_4	1001	3.000434077
09/09/2019 19:00	ALERT_Sys_5	983	2.992553518
10/09/2019 10:29	ALERT_Sys_1	303	2.481442629
10/09/2019 10:38	ALERT_Sys_2	868	2.938519725

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10/09/2019 12:59	ALERT_Sys_3	739	2.868644438
10/09/2019 14:31	ALERT_Sys_4	473	2.674861141
10/09/2019 16:01	ALERT_Sys_5	258	2.411619706
10/09/2019 17:31	ALERT_Sys_6	739	2.868644438
10/09/2019 19:01	ALERT_Sys_7	473	2.674861141
11/09/2019 10:56	ALERT_Sys_1	852	2.930439595
11/09/2019 11:06	ALERT_Sys_2	618	2.790988475
11/09/2019 12:59	ALERT_Sys_3	303	2.481442629
11/09/2019 14:29	ALERT_Sys_4	641	2.80685803
11/09/2019 16:00	ALERT_Sys_5	1001	3.000434077
11/09/2019 17:30	ALERT_Sys_6	473	2.674861141
11/09/2019 19:00	ALERT_Sys_7	473	2.674861141
12/09/2019 11:29	ALERT_Sys_1	739	2.868644438
12/09/2019 11:33	ALERT_Sys_2	1001	3.000434077
12/09/2019 13:05	ALERT_Sys_3	258	2.411619706
12/09/2019 14:31	ALERT_Sys_4	739	2.868644438
12/09/2019 15:59	ALERT_Sys_5	868	2.938519725
12/09/2019 17:31	ALERT_Sys_6	224	2.350248018
12/09/2019 19:00	ALERT_Sys_7	555	2.744292983
13/09/2019 11:32	ALERT_Sys_1	739	2.868644438
13/09/2019 11:46	ALERT_Sys_2	868	2.938519725
13/09/2019 17:30	ALERT_Sys_3	69	1.838849091
14/09/2019 09:00	ALERT_Sys_1	868	2.938519725
14/09/2019 17:31	ALERT_Sys_2	641	2.80685803
15/09/2019 09:00	ALERT_Sys_1	1001	3.000434077
15/09/2019 17:31	ALERT_Sys_2	641	2.80685803
16/09/2019 11:32	ALERT_Sys_1	410	2.612783857
16/09/2019 12:11	ALERT_Sys_2	465	2.667452953
16/09/2019 12:59	ALERT_Sys_3	555	2.744292983
16/09/2019 14:29	ALERT_Sys_4	403	2.605305046
16/09/2019 16:03	ALERT_Sys_5	641	2.80685803
16/09/2019 17:31	ALERT_Sys_6	555	2.744292983
16/09/2019 19:01	ALERT_Sys_7	473	2.674861141
17/09/2019 11:14	ALERT_Sys_1	739	2.868644438
17/09/2019 11:26	ALERT_Sys_2	224	2.350248018
17/09/2019 12:59	ALERT_Sys_3	629	2.798650645
17/09/2019 14:31	ALERT_Sys_4	124	2.093421685
17/09/2019 16:01	ALERT_Sys_5	303	2.481442629
17/09/2019 17:31	ALERT_Sys_6	224	2.350248018
17/09/2019 19:01	ALERT_Sys_7	343	2.53529412
18/09/2019 11:19	ALERT_Sys_1	228	2.357934847
18/09/2019 11:28	ALERT_Sys_2	473	2.674861141
18/09/2019 13:00	ALERT_Sys_3	303	2.481442629
18/09/2019 14:31	ALERT_Sys_4	94	1.973127854
18/09/2019 16:01	ALERT_Sys_5	224	2.350248018
18/09/2019 17:30	ALERT_Sys_6	228	2.357934847
18/09/2019 19:01	ALERT_Sys_7	403	2.605305046
19/09/2019 11:34	ALERT_Sys_1	868	2.938519725
19/09/2019 11:45	ALERT_Sys_2	546	2.737192643

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19/09/2019 12:59	no_sample		
19/09/2019 14:31	ALERT_Sys_4	629	2.798650645
19/09/2019 16:01	ALERT_Sys_5	465	2.667452953
19/09/2019 17:31	ALERT_Sys_6	726	2.860936621
19/09/2019 19:00	ALERT_Sys_7	410	2.612783857
20/09/2019 12:02	ALERT_Sys_1	739	2.868644438
20/09/2019 12:10	ALERT_Sys_2	224	2.350248018
20/09/2019 17:30	ALERT_Sys_3	473	2.674861141
21/09/2019 09:00	ALERT_Sys_1	396	2.597695186
21/09/2019 17:30	ALERT_Sys_2	303	2.481442629
22/09/2019 09:00	ALERT_Sys_1	396	2.597695186
22/09/2019 17:30	ALERT_Sys_2	108	2.033423755
23/09/2019 11:07	ALERT_Sys_1	194	2.28780173
23/09/2019 11:23	ALERT_Sys_2	555	2.744292983
23/09/2019 12:59	ALERT_Sys_3	80	1.903089987
23/09/2019 14:29	ALERT_Sys_4	403	2.605305046
23/09/2019 16:00	ALERT_Sys_5	473	2.674861141
23/09/2019 17:30	ALERT_Sys_6	106	2.025305865
23/09/2019 19:00	ALERT_Sys_7	298	2.474216264
24/09/2019 10:59	ALERT_Sys_1	410	2.612783857
24/09/2019 11:15	ALERT_Sys_2	349	2.542825427
24/09/2019 13:00	ALERT_Sys_3	50	1.698970004
24/09/2019 14:30	ALERT_Sys_4	263	2.419955748
24/09/2019 16:00	ALERT_Sys_5	90	1.954242509
24/09/2019 17:30	ALERT_Sys_6	224	2.350248018
24/09/2019 19:00	ALERT_Sys_7	298	2.474216264
25/09/2019 11:31	ALERT_Sys_1	141	2.149219113
25/09/2019 11:46	ALERT_Sys_2	356	2.551449998
25/09/2019 12:59	ALERT_Sys_3	303	2.481442629
25/09/2019 14:29	ALERT_Sys_4	224	2.350248018
25/09/2019 16:01	ALERT_Sys_5	641	2.80685803
25/09/2019 17:31	ALERT_Sys_6	726	2.860936621
25/09/2019 19:01	ALERT_Sys_7	141	2.149219113
26/09/2019 10:34	ALERT_Sys_1	641	2.80685803
26/09/2019 10:46	ALERT_Sys_2	852	2.930439595
26/09/2019 13:00	ALERT_Sys_3	1134	3.054613055
26/09/2019 14:30	ALERT_Sys_4	349	2.542825427
26/09/2019 16:00	ALERT_Sys_5	868	2.938519725
26/09/2019 17:30	ALERT_Sys_6	629	2.798650645
26/09/2019 19:00	ALERT_Sys_7	465	2.667452953
27/09/2019 11:11	ALERT_Sys_1	303	2.481442629
27/09/2019 11:29	ALERT_Sys_2	739	2.868644438
27/09/2019 17:30	ALERT_Sys_3	2819	3.450095076
28/09/2019 09:00	ALERT_Sys_1	473	2.674861141
28/09/2019 17:31	ALERT_Sys_2	2444	3.388101202
29/09/2019 09:00	ALERT_Sys_1	1001	3.000434077
29/09/2019 17:30	ALERT_Sys_2	473	2.674861141
08/08/2019 08:31	LAB_1.1	759	2.880241776
08/08/2019 09:00	LAB_2.1	554	2.743509765

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08/08/2019 17:00	no_sample		
09/08/2019 11:13	LAB_1.1	580	2.763427994
09/08/2019 11:45	LAB_2.1	539	2.731588765
10/08/2019 09:00	no_sample		
10/08/2019 17:01	no_sample		
11/08/2019 09:00	no_sample		
11/08/2019 17:00	no_sample		
12/08/2019 13:29	no_sample		
12/08/2019 14:30	no_sample		
13/08/2019 09:10	LAB_1.1	350	2.544068044
13/08/2019 10:15	LAB_2.1	350	2.544068044
13/08/2019 17:00	no_sample		
14/08/2019 12:20	LAB_1.1	453	2.656098202
14/08/2019 12:34	LAB_2.1	371	2.56937391
14/08/2019 17:00	no_sample		
15/08/2019 09:23	LAB_1.1	375	2.574031268
15/08/2019 10:12	LAB_2.1	393	2.59439255
15/08/2019 17:00	no_sample		
16/08/2019 11:02	LAB_1.1	249	2.396199347
16/08/2019 11:39	LAB_2.1	253	2.403120521
16/08/2019 17:00	no_sample		
17/08/2019 09:00	no_sample		
17/08/2019 17:01	no_sample		
18/08/2019 09:00	no_sample		
18/08/2019 17:00	no_sample		
19/08/2019 11:11	LAB_1.1	2140	3.330413773
19/08/2019 11:19	LAB_2.1	2130	3.328379603
19/08/2019 13:57	no_sample		
19/08/2019 15:00	no_sample		
19/08/2019 17:00	no_sample		
19/08/2019 18:01	no_sample		
19/08/2019 19:01	no_sample		
20/08/2019 11:23	LAB_1.1	363	2.559906625
20/08/2019 11:29	LAB_2.1	424	2.627365857
20/08/2019 13:03	no_sample		
20/08/2019 14:30	no_sample		
20/08/2019 16:00	no_sample		
20/08/2019 17:31	no_sample		
20/08/2019 19:00	no_sample		
21/08/2019 11:11	LAB_1.1	554	2.743509765
21/08/2019 11:24	LAB_2.1	476	2.677606953
21/08/2019 12:58	no_sample		
21/08/2019 14:28	no_sample		
21/08/2019 16:00	no_sample		
21/08/2019 17:30	no_sample		
21/08/2019 19:00	no_sample		
22/08/2019 11:20	LAB_1.1	251	2.399673721
22/08/2019 11:28	LAB_2.1	232	2.365487985
22/08/2019 13:00	no_sample		

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22/08/2019 14:30	no_sample		
22/08/2019 16:27	no_sample		
22/08/2019 17:31	no_sample		
22/08/2019 19:01	no_sample		
23/08/2019 11:03	LAB_1.1	350	2.544068044
23/08/2019 11:13	LAB_2.1	232	2.365487985
23/08/2019 19:00	no_sample		
24/08/2019 09:00	no_sample		
24/08/2019 17:01	no_sample		
25/08/2019 09:00	no_sample		
25/08/2019 17:01	no_sample		
26/08/2019 10:40	LAB_1.1	368	2.565847819
26/08/2019 10:49	LAB_2.1	253	2.403120521
26/08/2019 12:59	no_sample		
26/08/2019 14:31	no_sample		
26/08/2019 16:00	no_sample		
26/08/2019 17:30	no_sample		
26/08/2019 19:00	no_sample		
27/08/2019 12:51	LAB_1.1	419	2.622214023
27/08/2019 13:13	LAB_2.1	270	2.431363764
27/08/2019 15:17	no_sample		
27/08/2019 16:00	no_sample		
27/08/2019 17:00	no_sample		
27/08/2019 18:00	no_sample		
27/08/2019 19:01	no_sample		
28/08/2019 10:47	LAB_1.1	272	2.434568904
28/08/2019 10:50	LAB_2.1	270	2.431363764
28/08/2019 11:01	no_sample		
28/08/2019 17:01	no_sample		
29/08/2019 09:00	no_sample		
29/08/2019 13:00	no_sample		
29/08/2019 17:00	no_sample		
30/08/2019 11:02	LAB_1.1	292	2.465382851
30/08/2019 11:11	LAB_2.1	287	2.457881897
31/08/2019 09:00	no_sample		
31/08/2019 17:30	no_sample		
01/09/2019 09:00	no_sample		
01/09/2019 17:30	no_sample		
01/09/2019 19:01	no_sample		
02/09/2019 11:35	LAB_1.1	419	2.622214023
02/09/2019 12:03	LAB_2.1	412	2.614897216
02/09/2019 13:00	no_sample		
02/09/2019 14:30	no_sample		
02/09/2019 16:06	no_sample		
02/09/2019 17:30	no_sample		
02/09/2019 19:01	no_sample		
03/09/2019 12:09	LAB_1.1	332	2.521138084
03/09/2019 12:17	LAB_2.1	457	2.6599162
03/09/2019 14:28	no_sample		

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03/09/2019 16:00	no_sample		
03/09/2019 17:30	no_sample		
03/09/2019 19:00	no_sample		
04/09/2019 11:26	LAB_1.1	324	2.51054501
04/09/2019 11:47	LAB_2.1	383	2.583198774
04/09/2019 12:59	no_sample		
04/09/2019 14:29	no_sample		
04/09/2019 17:30	no_sample		
04/09/2019 19:00	no_sample		
05/09/2019 11:09	no_sample		
05/09/2019 11:49	LAB_1.1	534	2.727541257
05/09/2019 12:03	LAB_2.1	461	2.663700925
05/09/2019 12:48	no_sample		
05/09/2019 12:50	no_sample		
06/09/2019 10:43	LAB_1.1	568	2.754348336
06/09/2019 10:59	LAB_2.1	534	2.727541257
06/09/2019 17:30	no_sample		
07/09/2019 09:00	no_sample		
07/09/2019 17:31	no_sample		
08/09/2019 09:00	no_sample		
08/09/2019 17:30	no_sample		
09/09/2019 12:46	LAB_1.1	647	2.810904281
09/09/2019 12:59	LAB_2.1	640	2.806179974
09/09/2019 14:29	no_sample		
09/09/2019 17:30	no_sample		
09/09/2019 19:00	no_sample		
10/09/2019 10:29	LAB_1.1	627	2.797267541
10/09/2019 10:38	LAB_2.1	559	2.747411808
10/09/2019 12:59	no_sample		
10/09/2019 14:31	no_sample		
10/09/2019 16:01	no_sample		
10/09/2019 17:31	no_sample		
10/09/2019 19:01	no_sample		
11/09/2019 10:56	LAB_1.1	272	2.434568904
11/09/2019 11:06	LAB_2.1	438	2.641474111
11/09/2019 12:59	no_sample		
11/09/2019 14:29	no_sample		
11/09/2019 16:00	no_sample		
11/09/2019 17:30	no_sample		
11/09/2019 19:00	no_sample		
12/09/2019 11:29	LAB_1.1	329	2.517195898
12/09/2019 11:33	LAB_2.1	162	2.209515015
12/09/2019 13:05	no_sample		
12/09/2019 14:31	no_sample		
12/09/2019 15:59	no_sample		
12/09/2019 17:31	no_sample		
12/09/2019 19:00	no_sample		
13/09/2019 11:32	LAB_1.1	419	2.622214023
13/09/2019 11:46	LAB_2.1	312	2.494154594

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13/09/2019 17:30	no_sample		
14/09/2019 09:00	no_sample		
14/09/2019 17:31	no_sample		
15/09/2019 09:00	no_sample		
15/09/2019 17:31	no_sample		
16/09/2019 11:32	LAB_1.1	368	2.565847819
16/09/2019 12:11	LAB_2.1	415	2.618048097
16/09/2019 12:59	no_sample		
16/09/2019 14:29	no_sample		
16/09/2019 16:03	no_sample		
16/09/2019 17:31	no_sample		
16/09/2019 19:01	no_sample		
17/09/2019 11:14	LAB_1.1	142	2.152288344
17/09/2019 11:26	LAB_2.1	177	2.247973266
17/09/2019 12:59	no_sample		
17/09/2019 14:31	no_sample		
17/09/2019 16:01	no_sample		
17/09/2019 17:31	no_sample		
17/09/2019 19:01	no_sample		
18/09/2019 11:19	LAB_1.1	270	2.431363764
18/09/2019 11:28	LAB_2.1	215	2.33243846
18/09/2019 13:00	no_sample		
18/09/2019 14:31	no_sample		
18/09/2019 16:01	no_sample		
18/09/2019 17:30	no_sample		
18/09/2019 19:01	no_sample		
19/09/2019 11:34	LAB_1.1	620	2.792391689
19/09/2019 11:45	LAB_2.1	530	2.72427587
19/09/2019 12:59	no_sample		
19/09/2019 14:31	no_sample		
19/09/2019 16:01	no_sample		
19/09/2019 17:31	no_sample		
19/09/2019 19:00	no_sample		
20/09/2019 12:02	LAB_1.1	285	2.45484486
20/09/2019 12:10	LAB_2.1	504	2.702430536
20/09/2019 17:30	no_sample		
21/09/2019 09:00	no_sample		
21/09/2019 17:30	no_sample		
22/09/2019 09:00	no_sample		
22/09/2019 17:30	no_sample		
23/09/2019 11:07	LAB_1.1	307	2.487138375
23/09/2019 11:23	LAB_2.1	212	2.326335861
23/09/2019 12:59	no_sample		
23/09/2019 14:29	no_sample		
23/09/2019 16:00	no_sample		
23/09/2019 17:30	no_sample		
23/09/2019 19:00	no_sample		
24/09/2019 10:59	LAB_1.1	176	2.245512668
24/09/2019 11:15	LAB_2.1	109	2.037426498

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24/09/2019 13:00	no_sample		
24/09/2019 14:30	no_sample		
24/09/2019 16:00	no_sample		
24/09/2019 17:30	no_sample		
24/09/2019 19:00	no_sample		
25/09/2019 11:31	LAB_1.1	415	2.618048097
25/09/2019 11:46	LAB_2.1	289	2.460897843
25/09/2019 12:59	no_sample		
25/09/2019 14:29	no_sample		
25/09/2019 16:01	no_sample		
25/09/2019 17:31	no_sample		
25/09/2019 19:01	no_sample		
26/09/2019 10:34	LAB_1.1	213	2.328379603
26/09/2019 10:46	LAB_2.1	372	2.57054294
26/09/2019 13:00	no_sample		
26/09/2019 14:30	no_sample		
26/09/2019 16:00	no_sample		
26/09/2019 17:30	no_sample		
26/09/2019 19:00	no_sample		
27/09/2019 11:11	LAB_1.1	461	2.663700925
27/09/2019 11:29	LAB_2.1	390	2.591064607
27/09/2019 17:30	no_sample		
28/09/2019 09:00	no_sample		
28/09/2019 17:31	no_sample		
29/09/2019 09:00	no_sample		
29/09/2019 17:30	no_sample		

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Table A4: Data from Berlin repeatability study 2020 (ALERT SYSTEM, ALERT LAB, LAB)

Sampling date	Label	Count CFU/100 mL	Log10 (count)
11.09.2020	AGROLAB_DS1	15	1.176091259
11.09.2020	AGROLAB_DS2	0.1	-1
11.09.2020	AGROLAB_DS3	0.1	-1
11.09.2020	AGROLAB_DS4	15	1.176091259
11.09.2020	AGROLAB_DS5	0.1	-1
11.09.2020	AGROLAB_DS6	0.1	-1
11.09.2020	AGROLAB_DS7	30	1.477121255
11.09.2020	AGROLAB_DS8	0.1	-1
11.09.2020	AGROLAB_DS9	15	1.176091259
11.09.2020	AGROLAB_DS10	0.1	-1
11.09.2020	AGROLAB_DS11	0.1	-1
11.09.2020	AGROLAB_DS12	0.1	-1
11.09.2020	LLBB_DS1	15	1.176091259
11.09.2020	LLBB_DS2	30	1.477121255
11.09.2020	LLBB_DS3	15	1.176091259
11.09.2020	LLBB_DS4	0.1	-1
11.09.2020	LLBB_DS5	15	1.176091259
11.09.2020	LLBB_DS6	0.1	-1
11.09.2020	LLBB_DS7	15	1.176091259
11.09.2020	LLBB_DS8	0.1	-1
11.09.2020	LLBB_DS9	30	1.477121255
11.09.2020	LLBB_DS10	0.1	-1
11.09.2020	LLBB_DS11	0.1	-1
11.09.2020	LLBB_DS12	0.1	-1
11.09.2020	ALERT_Sys_DS1	0.1	-1
11.09.2020	ALERT_Sys_DS2	0.1	-1
11.09.2020	ALERT_Sys_DS3	0.1	-1
11.09.2020	ALERT_Sys_DS4	0.1	-1
11.09.2020	ALERT_Sys_DS5	0.1	-1
11.09.2020	ALERT_Sys_DS6	0.1	-1
11.09.2020	ALERT_Sys_DS7	0.1	-1
11.09.2020	ALERT_Lab_DS1	4	0.602059991
11.09.2020	ALERT_Lab_DS2	0.1	-1
11.09.2020	ALERT_Lab_DS3	4	0.602059991
11.09.2020	ALERT_Lab_DS4	0.1	-1
11.09.2020	ALERT_Lab_DS5	0.1	-1
11.09.2020	ALERT_Lab_DS6	0.1	-1
14.09.2020	AGROLAB_DS1	197	2.294466226
14.09.2020	AGROLAB_DS2	160	2.204119983
14.09.2020	AGROLAB_DS3	144	2.158362492
14.09.2020	AGROLAB_DS4	110	2.041392685
14.09.2020	AGROLAB_DS5	94	1.973127854
14.09.2020	AGROLAB_DS6	179	2.252853031
14.09.2020	AGROLAB_DS7	127	2.103803721
14.09.2020	AGROLAB_DS8	161	2.206825876
14.09.2020	AGROLAB_DS9	176	2.245512668
14.09.2020	AGROLAB_DS10	127	2.103803721

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14.09.2020	AGROLAB_DS11	160	2.204119983
14.09.2020	AGROLAB_DS12	77	1.886490725
14.09.2020	LLBB_DS1	197	2.294466226
14.09.2020	LLBB_DS2	195	2.290034611
14.09.2020	LLBB_DS3	94	1.973127854
14.09.2020	LLBB_DS4	94	1.973127854
14.09.2020	LLBB_DS5	110	2.041392685
14.09.2020	LLBB_DS6	144	2.158362492
14.09.2020	LLBB_DS7	127	2.103803721
14.09.2020	LLBB_DS8	160	2.204119983
14.09.2020	LLBB_DS9	215	2.33243846
14.09.2020	LLBB_DS10	197	2.294466226
14.09.2020	LLBB_DS11	143	2.155336037
14.09.2020	LLBB_DS12	210	2.322219295
14.09.2020	ALERT_Sys_DS1		
14.09.2020	ALERT_Sys_DS2		
14.09.2020	ALERT_Sys_DS3		
14.09.2020	ALERT_Sys_DS4		
14.09.2020	ALERT_Sys_DS5		
14.09.2020	ALERT_Sys_DS6		
14.09.2020	ALERT_Sys_DS7		
14.09.2020	ALERT_Lab_DS1	389	2.589949601
14.09.2020	ALERT_Lab_DS2	382	2.582063363
14.09.2020	ALERT_Lab_DS3	292	2.465382851
14.09.2020	ALERT_Lab_DS4	253	2.403120521
14.09.2020	ALERT_Lab_DS5	287	2.457881897
14.09.2020	ALERT_Lab_DS6	555	2.744292983
18.09.2020	AGROLAB_DS1	489	2.689308859
18.09.2020	AGROLAB_DS2	438	2.641474111
18.09.2020	AGROLAB_DS3	491	2.691081492
18.09.2020	AGROLAB_DS4	350	2.544068044
18.09.2020	AGROLAB_DS5	476	2.677606953
18.09.2020	AGROLAB_DS6	453	2.656098202
18.09.2020	AGROLAB_DS7	430	2.633468456
18.09.2020	AGROLAB_DS8	523	2.718501689
18.09.2020	AGROLAB_DS9	427	2.630427875
18.09.2020	AGROLAB_DS10	438	2.641474111
18.09.2020	AGROLAB_DS11	559	2.747411808
18.09.2020	AGROLAB_DS12	408	2.610660163
18.09.2020	LLBB_DS1	485	2.685741739
18.09.2020	LLBB_DS2	453	2.656098202
18.09.2020	LLBB_DS3	627	2.797267541
18.09.2020	LLBB_DS4	419	2.622214023
18.09.2020	LLBB_DS5	509	2.706717782
18.09.2020	LLBB_DS6	489	2.689308859
18.09.2020	LLBB_DS7	332	2.521138084
18.09.2020	LLBB_DS8	524	2.719331287
18.09.2020	LLBB_DS9	720	2.857332496
18.09.2020	LLBB_DS10	549	2.739572344

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18.09.2020	LLBB_DS11	480	2.681241237
18.09.2020	LLBB_DS12	514	2.710963119
18.09.2020	ALERT_Sys_DS1	2533	3.40363519
18.09.2020	ALERT_Sys_DS2	410	2.612783857
18.09.2020	ALERT_Sys_DS3	369	2.567026366
18.09.2020	ALERT_Sys_DS4	240	2.380211242
18.09.2020	ALERT_Sys_DS5	701	2.845718018
18.09.2020	ALERT_Sys_DS6	191	2.281033367
18.09.2020	ALERT_Sys_DS7	2444	3.388101202
18.09.2020	ALERT_Lab_DS1	1134	3.054613055
18.09.2020	ALERT_Lab_DS2	726	2.860936621
18.09.2020	ALERT_Lab_DS3	713	2.85308953
18.09.2020	ALERT_Lab_DS4	1482	3.170848204
18.09.2020	ALERT_Lab_DS5	576	2.760422483
18.09.2020	ALERT_Lab_DS6	916	2.961895474
21.09.2020	AGROLAB_DS1	1327	3.122870923
21.09.2020	AGROLAB_DS2	1148	3.059941888
21.09.2020	AGROLAB_DS3	1327	3.122870923
21.09.2020	AGROLAB_DS4	1120	3.049218023
21.09.2020	AGROLAB_DS5	848	2.928395852
21.09.2020	AGROLAB_DS6	1414	3.150449409
21.09.2020	AGROLAB_DS7	1274	3.105169428
21.09.2020	AGROLAB_DS8	981	2.991669007
21.09.2020	AGROLAB_DS9	1160	3.064457989
21.09.2020	AGROLAB_DS10	1327	3.122870923
21.09.2020	AGROLAB_DS11	1327	3.122870923
21.09.2020	AGROLAB_DS12	1264	3.101747074
21.09.2020	LLBB_DS1	1440	3.158362492
21.09.2020	LLBB_DS2	1177	3.070776463
21.09.2020	LLBB_DS3	1531	3.184975191
21.09.2020	LLBB_DS4	1976	3.29578694
21.09.2020	LLBB_DS5	1931	3.285782274
21.09.2020	LLBB_DS6	1567	3.195068996
21.09.2020	LLBB_DS7	1132	3.053846427
21.09.2020	LLBB_DS8	1754	3.244029589
21.09.2020	LLBB_DS9	1567	3.195068996
21.09.2020	LLBB_DS10	1076	3.031812271
21.09.2020	LLBB_DS11	1213	3.083860801
21.09.2020	LLBB_DS12	968	2.985875357
21.09.2020	ALERT_Sys_DS1	2625	3.419129308
21.09.2020	ALERT_Sys_DS2	2008	3.302763708
21.09.2020	ALERT_Sys_DS3	1804	3.256236533
21.09.2020	ALERT_Sys_DS4	2488	3.395850376
21.09.2020	ALERT_Sys_DS5	4029	3.605197267
21.09.2020	ALERT_Sys_DS6	726	2.860936621
21.09.2020	ALERT_Sys_DS7	3751	3.574147064
21.09.2020	ALERT_Lab_DS1	3028	3.481155871
21.09.2020	ALERT_Lab_DS2	2578	3.411282913
21.09.2020	ALERT_Lab_DS3	2533	3.40363519

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21.09.2020	ALERT_Lab_DS4	2922	3.465680212
21.09.2020	ALERT_Lab_DS5	1650	3.217483944
21.09.2020	ALERT_Lab_DS6	3685	3.566437492
22.09.2020	AGROLAB_DS1	2675	3.427323786
22.09.2020	AGROLAB_DS2	2428	3.385248682
22.09.2020	AGROLAB_DS3	2305	3.36267093
22.09.2020	AGROLAB_DS4	3534	3.548266545
22.09.2020	AGROLAB_DS5	4006	3.602710945
22.09.2020	AGROLAB_DS6	3113	3.493179121
22.09.2020	AGROLAB_DS7	3213	3.506910726
22.09.2020	AGROLAB_DS8	2844	3.453929592
22.09.2020	AGROLAB_DS9	4369	3.640382045
22.09.2020	AGROLAB_DS10	3197	3.504742636
22.09.2020	AGROLAB_DS11	4275	3.630936119
22.09.2020	AGROLAB_DS12	2716	3.433929766
22.09.2020	LLBB_DS1	4753	3.676967814
22.09.2020	LLBB_DS2	3132	3.495821753
22.09.2020	LLBB_DS3	3422	3.534280005
22.09.2020	LLBB_DS4	3421	3.534153074
22.09.2020	LLBB_DS5	2639	3.42143939
22.09.2020	LLBB_DS6	3552	3.550472957
22.09.2020	LLBB_DS7	3212	3.506775537
22.09.2020	LLBB_DS8	2422	3.384174139
22.09.2020	LLBB_DS9	2792	3.445915414
22.09.2020	LLBB_DS10	3889	3.589837943
22.09.2020	LLBB_DS11	2873	3.458335626
22.09.2020	LLBB_DS12	3693	3.567379308
22.09.2020	ALERT_Sys_DS1	11800	4.071882007
22.09.2020	ALERT_Sys_DS2	18100	4.257678575
22.09.2020	ALERT_Sys_DS3	3958	3.59747579
22.09.2020	ALERT_Sys_DS4	5968	3.775828814
22.09.2020	ALERT_Sys_DS5	26700	4.426511261
22.09.2020	ALERT_Sys_DS6	3819	3.581949658
22.09.2020	ALERT_Sys_DS7		
22.09.2020	ALERT_Lab_DS1	9665	3.985201858
22.09.2020	ALERT_Lab_DS2	7663	3.884398826
22.09.2020	ALERT_Lab_DS3	6296	3.799064719
22.09.2020	ALERT_Lab_DS4	6185	3.791339704
22.09.2020	ALERT_Lab_DS5	9161	3.961942883
22.09.2020	ALERT_Lab_DS6	11300	4.053078443
23.09.2020	AGROLAB_DS1	3019	3.479863113
23.09.2020	AGROLAB_DS2	3297	3.518118947
23.09.2020	AGROLAB_DS3	3534	3.548266545
23.09.2020	AGROLAB_DS4	3019	3.479863113
23.09.2020	AGROLAB_DS5	2956	3.47070443
23.09.2020	AGROLAB_DS6	3197	3.504742636
23.09.2020	AGROLAB_DS7	2675	3.427323786
23.09.2020	AGROLAB_DS8	2716	3.433929766
23.09.2020	AGROLAB_DS9	3844	3.584783379

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23.09.2020	AGROLAB_DS10	4075	3.610127613
23.09.2020	AGROLAB_DS11	3197	3.504742636
23.09.2020	AGROLAB_DS12	2641	3.421768401
23.09.2020	LLBB_DS1	2823	3.450710878
23.09.2020	LLBB_DS2	2150	3.33243846
23.09.2020	LLBB_DS3	3093	3.49037992
23.09.2020	LLBB_DS4	2639	3.42143939
23.09.2020	LLBB_DS5	4753	3.676967814
23.09.2020	LLBB_DS6	2929	3.466719372
23.09.2020	LLBB_DS7	3543	3.549371152
23.09.2020	LLBB_DS8	3181	3.502563669
23.09.2020	LLBB_DS9	3042	3.48315921
23.09.2020	LLBB_DS10	3421	3.534153074
23.09.2020	LLBB_DS11	2956	3.47070443
23.09.2020	LLBB_DS12	3020	3.480006943
23.09.2020	ALERT_Sys_DS1	5862	3.768045814
23.09.2020	ALERT_Sys_DS2	5267	3.721563318
23.09.2020	ALERT_Sys_DS3	2974	3.473340964
23.09.2020	ALERT_Sys_DS4	4732	3.675044736
23.09.2020	ALERT_Sys_DS5	8839	3.946403134
23.09.2020	ALERT_Sys_DS6	2401	3.38039216
23.09.2020	ALERT_Sys_DS7	7135	3.853393977
23.09.2020	ALERT_Lab_DS1	7527	3.876621916
23.09.2020	ALERT_Lab_DS2	5758	3.760271661
23.09.2020	ALERT_Lab_DS3	5082	3.706034661
23.09.2020	ALERT_Lab_DS4	7135	3.853393977
23.09.2020	ALERT_Lab_DS5	6185	3.791339704
23.09.2020	ALERT_Lab_DS6	6884	3.837840862
24.09.2020	AGROLAB_DS1	9050	3.956648579
24.09.2020	AGROLAB_DS2	9050	3.956648579
24.09.2020	AGROLAB_DS3	9050	3.956648579
24.09.2020	AGROLAB_DS4	18550	4.268343914
24.09.2020	AGROLAB_DS5	9050	3.956648579
24.09.2020	AGROLAB_DS6	16750	4.224014811
24.09.2020	AGROLAB_DS7	9050	3.956648579
24.09.2020	AGROLAB_DS8	12700	4.103803721
24.09.2020	AGROLAB_DS9	11625	4.065392962
24.09.2020	AGROLAB_DS10	12700	4.103803721
24.09.2020	AGROLAB_DS11	13863	4.141857223
24.09.2020	AGROLAB_DS12	9050	3.956648579
24.09.2020	LLBB_DS1	13864	4.14188855
24.09.2020	LLBB_DS2	13864	4.14188855
24.09.2020	LLBB_DS3	8329	3.920592862
24.09.2020	LLBB_DS4	8329	3.920592862
24.09.2020	LLBB_DS5	11636	4.065803713
24.09.2020	LLBB_DS6	7683	3.885530833
24.09.2020	LLBB_DS7	9826	3.99237676
24.09.2020	LLBB_DS8	8513	3.930082633
24.09.2020	LLBB_DS9	12687	4.10335894

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24.09.2020	LLBB_DS10	9826	3.99237676
24.09.2020	LLBB_DS11	11636	4.065803713
24.09.2020	LLBB_DS12	8329	3.920592862
24.09.2020	ALERT_Sys_DS1	11000	4.041392685
24.09.2020	ALERT_Sys_DS2	4485	3.651762447
24.09.2020	ALERT_Sys_DS3	4029	3.605197267
24.09.2020	ALERT_Sys_DS4	12400	4.093421685
24.09.2020	ALERT_Sys_DS5	8084	3.907626305
24.09.2020	ALERT_Sys_DS6	8378	3.923140356
24.09.2020	ALERT_Sys_DS7	16500	4.217483944
24.09.2020	ALERT_Lab_DS1	21600	4.334453751
24.09.2020	ALERT_Lab_DS2	12200	4.086359831
24.09.2020	ALERT_Lab_DS3	12000	4.079181246
24.09.2020	ALERT_Lab_DS4	17700	4.247973266
24.09.2020	ALERT_Lab_DS5	13300	4.123851641
24.09.2020	ALERT_Lab_DS6	19700	4.294466226
28.09.2020	AGROLAB_DS1	144	2.158362492
28.09.2020	AGROLAB_DS2	110	2.041392685
28.09.2020	AGROLAB_DS3	94	1.973127854
28.09.2020	AGROLAB_DS4	195	2.290034611
28.09.2020	AGROLAB_DS5	76	1.880813592
28.09.2020	AGROLAB_DS6	144	2.158362492
28.09.2020	AGROLAB_DS7	110	2.041392685
28.09.2020	AGROLAB_DS8	197	2.294466226
28.09.2020	AGROLAB_DS9	110	2.041392685
28.09.2020	AGROLAB_DS10	77	1.886490725
28.09.2020	AGROLAB_DS11	161	2.206825876
28.09.2020	AGROLAB_DS12	61	1.785329835
28.09.2020	LLBB_DS1	272	2.434568904
28.09.2020	LLBB_DS2	94	1.973127854
28.09.2020	LLBB_DS3	144	2.158362492
28.09.2020	LLBB_DS4	77	1.886490725
28.09.2020	LLBB_DS5	77	1.886490725
28.09.2020	LLBB_DS6	110	2.041392685
28.09.2020	LLBB_DS7	144	2.158362492
28.09.2020	LLBB_DS8	143	2.155336037
28.09.2020	LLBB_DS9	126	2.100370545
28.09.2020	LLBB_DS10	179	2.252853031
28.09.2020	LLBB_DS11	127	2.103803721
28.09.2020	LLBB_DS12		
28.09.2020	ALERT_Sys_DS1	95	1.977723605
28.09.2020	ALERT_Sys_DS2	74	1.86923172
28.09.2020	ALERT_Sys_DS3	39	1.591064607
28.09.2020	ALERT_Sys_DS4	508	2.705863712
28.09.2020	ALERT_Sys_DS5	37	1.568201724
28.09.2020	ALERT_Sys_DS6	4	0.602059991
28.09.2020	ALERT_Sys_DS7		
28.09.2020	ALERT_Lab_DS1	308	2.488550717
28.09.2020	ALERT_Lab_DS2	236	2.372912003

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28.09.2020	ALERT_Lab_DS3	138	2.139879086
28.09.2020	ALERT_Lab_DS4	303	2.481442629
28.09.2020	ALERT_Lab_DS5	298	2.474216264
28.09.2020	ALERT_Lab_DS6	403	2.605305046
29.09.2020	AGROLAB_DS1	161	2.206825876
29.09.2020	AGROLAB_DS2	143	2.155336037
29.09.2020	AGROLAB_DS3	291	2.463892989
29.09.2020	AGROLAB_DS4	291	2.463892989
29.09.2020	AGROLAB_DS5	213	2.328379603
29.09.2020	AGROLAB_DS6	94	1.973127854
29.09.2020	AGROLAB_DS7	195	2.290034611
29.09.2020	AGROLAB_DS8	408	2.610660163
29.09.2020	AGROLAB_DS9	212	2.326335861
29.09.2020	AGROLAB_DS10	272	2.434568904
29.09.2020	AGROLAB_DS11	272	2.434568904
29.09.2020	AGROLAB_DS12	126	2.100370545
29.09.2020	LLBB_DS1	110	2.041392685
29.09.2020	LLBB_DS2	143	2.155336037
29.09.2020	LLBB_DS3	127	2.103803721
29.09.2020	LLBB_DS4	232	2.365487985
29.09.2020	LLBB_DS5	215	2.33243846
29.09.2020	LLBB_DS6	289	2.460897843
29.09.2020	LLBB_DS7	232	2.365487985
29.09.2020	LLBB_DS8	215	2.33243846
29.09.2020	LLBB_DS9	110	2.041392685
29.09.2020	LLBB_DS10	195	2.290034611
29.09.2020	LLBB_DS11	213	2.328379603
29.09.2020	LLBB_DS12	215	2.33243846
29.09.2020	ALERT_Sys_DS1	287	2.457881897
29.09.2020	ALERT_Sys_DS2	32	1.505149978
29.09.2020	ALERT_Sys_DS3	308	2.488550717
29.09.2020	ALERT_Sys_DS4	232	2.365487985
29.09.2020	ALERT_Sys_DS5	4	0.602059991
29.09.2020	ALERT_Sys_DS6	27	1.431363764
29.09.2020	ALERT_Sys_DS7		
29.09.2020	ALERT_Lab_DS1		
29.09.2020	ALERT_Lab_DS2		
29.09.2020	ALERT_Lab_DS3		
29.09.2020	ALERT_Lab_DS4		
29.09.2020	ALERT_Lab_DS5		
29.09.2020	ALERT_Lab_DS6		

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Table A5: Data from Paris Ablon deployment in 2021 (ALERT V2, LAB)

Date time	E. Coli SIAAP [MPN/100mL]	E. Coli Fluidion
01/06/21 10:02	1510	1537
04/06/21 03:58		541
04/06/21 12:00		27459
04/06/21 20:00		13691
05/06/21 04:00		32408
05/06/21 12:00		3082
05/06/21 20:00		2932
07/06/21 10:05		2287
08/06/21 10:01	1760	2611
09/06/21 10:02		9352
10/06/21 10:02		3822
11/06/21 10:01		3518
12/06/21 10:00		3886
13/06/21 10:00		
14/06/21 10:10		3348
15/06/21 09:50	1510	1415
17/06/21 21:09		31352
18/06/21 03:45		10856
18/06/21 10:33		6604
18/06/21 17:21		1844
19/06/21 00:09		
19/06/21 06:57		7174
19/06/21 13:45		935
22/06/21 09:39	1390	1814
23/06/21 10:02		4153
24/06/21 10:03		3082
25/06/21 10:05		2744
26/06/21 10:00		7416
27/06/21 10:00		2526
28/06/21 10:00		5237
29/06/21 10:09	2290	1589
30/06/21 10:06		2699
01/07/21 10:00		1199
02/07/21 10:06		1642
03/07/21 10:00		1085
04/07/21 10:00		8191
05/07/21 10:01		7174
06/07/21 10:09	1180	754
07/07/21 10:01		2744
08/07/21 10:05		1239
09/07/21 10:00		2611
10/07/21 10:00		3518
11/07/21 10:00		2485
12/07/21 10:00		1938
13/07/21 00:00	4540	
14/07/21 10:11		35208
15/07/21 10:03		11038

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16/07/21 10:04		2568
17/07/21 10:00		1487
18/07/21 10:00		2884
19/07/21 10:00		1368
20/07/21 09:12	619	1537
20/07/21 12:45		2071
20/07/21 16:15		983
20/07/21 19:45		1562
20/07/21 23:18		2526
21/07/21 02:45		2932
21/07/21 06:15		1462
22/07/21 10:21		2404
23/07/21 10:05		8328
24/07/21 10:00		2444
25/07/21 10:00		5237
26/07/21 10:00		1755
27/07/21 09:19	1510	2176
28/07/21 10:00		2140

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Table A6: Data from the first 2021 MILAN WWTP reuse campaign (ALERT V2, LAB)

Sampling date	Lab CFU/100mL	ALERT V2 EC/100mL (Beta 2)
2021-07-07 00:00	2.20E+03	3.08E+04
2021-07-08 09:30	4.00E+03	4.82E+04
2021-07-09 10:00	3.70E+03	2.45E+04
2021-07-12 11:20	4.00E+03	2.89E+04
2021-07-13 09:55	3.70E+03	2.93E+04
2021-07-14 10:00	2.60E+03	3.76E+04
2021-07-15 10:43	6.80E+02	1.07E+04
2021-07-20 10:15	6.00E+02	1.88E+04
2021-07-21 10:15	2.60E+03	2.66E+04
2021-07-22 10:00	7.10E+03	4.37E+04
2021-07-27 11:20	3.50E+03	4.51E+04
2021-07-28 10:45	8.00E+03	6.08E+04
2021-07-29 11:25	4.20E+03	2.79E+04
2021-08-02 12:00	4.00E+03	1.73E+04
2021-08-03 09:37	2.20E+03	2.37E+04
2021-08-04 10:00	7.40E+03	3.76E+04
2021-08-05 12:30	5.70E+03	2.04E+04
2021-08-09 12:40	1.80E+03	3.95E+04
2021-08-10 09:50	1.20E+03	8.19E+03
2021-08-12 09:55	4.90E+03	8.06E+04
2021-07-06 11:41		2.53E+04
2021-07-11 17:22		1.07E+05
2021-07-11 19:29		1.82E+05
2021-07-12 11:13		3.40E+04
2021-07-23 14:54		2.66E+04
2021-07-23 14:57		2.93E+04
2021-07-29 17:31		9.36E+04

Table A7: Data from the second 2021 MILAN WWTP reuse campaign (ALERT V2, ALERT V2 filtered, LAB)

Sampling date	Escherichia Coli		
	Laboratory data CFU/100mL	ALERT V2 EC/100mL	ALERT V2 + filter EC/100mL
2021-08-30 12:05	1.80E+03	1.49E+04	1.02E+04
2021-08-31 11:49	4.40E+03	3.46E+04	5.15E+03
2021-09-01 11:01	1.50E+03	5.16E+05	7.67E+03
2021-09-06 11:45	2.90E+03	3.08E+04	1.54E+04
2021-09-07 14:39	4.70E+03	6.83E+04	2.57E+04
2021-09-08 11:34	8.00E+02	7.42E+04	6.39E+03
2021-09-13 10:47	2.00E+03	1.30E+04	5.78E+03
2021-09-14 11:28	1.10E+03	2.98E+04	5.41E+03
2021-09-15 09:15	6.50E+03	1.97E+04	9.99E+03
2021-09-20 10:13	4.60E+03	2.04E+04	6.94E+03
2021-09-23 09:29	7.00E+03	2.37E+04	1.18E+04

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Table A8: Data from the 2021 repeatability campaign BERLIN 2021 (ALERT V2, LAB)

Dilution No	ALERT E coli QC	Log ALERT QC	Log Average ALERT QC	Log Std Alert QC	Lab value	Log lab	Log average lab	Log Std Lab
1	81	1.91	1.95	0.15	234	2.37	2.33	0.08
1	116	2.06			270	2.43		
1	76	1.88			197	2.29		
1	173	2.24			215	2.33		
1	73	1.86			161	2.21		
1	84	1.92			197	2.29		
1	60	1.78			270	2.43		
1					179	2.25		
2	279	2.45	2.37	0.12	375	2.57	2.55	0.05
2	249	2.40			272	2.43		
2	225	2.35			368	2.57		
2	308	2.49			327	2.51		
2	131	2.12			350	2.54		
2	218	2.34			350	2.54		
2	279	2.45			408	2.61		
2					383	2.58		
3	289	2.46	2.66	0.17	848	2.93	2.96	0.05
3	364	2.56			957	2.98		
3	319	2.50			1048	3.02		
3	532	2.73			781	2.89		
3	459	2.66			795	2.90		
3	608	2.78			969	2.99		
3	847	2.93			882	2.95		
3					968	2.99		
4	1844	3.27	3.29	0.08	3694	3.57	3.61	0.14
4	1875	3.27			3197	3.50		
4	1562	3.19			3838	3.58		
4	2003	3.30			3844	3.58		
4	2404	3.38			3019	3.48		
4	1726	3.24			7513	3.88		
4	2568	3.41			3334	3.52		
4					5713	3.76		
5	2404	3.38	3.32	0.08	3544	3.55	3.60	0.08
5	1438	3.16			3316	3.52		
5	2364	3.37			4369	3.64		
5	2213	3.34			4750	3.68		
5	1784	3.25			3316	3.52		
5	2287	3.36			5713	3.76		
5	2213	3.34			3806	3.58		
5					3844	3.58		
6	5413	3.73	3.70	0.06	8325	3.92	3.98	0.08
6	5881	3.77			7688	3.89		
6	3951	3.60			7100	3.85		
6	4983	3.70			10688	4.03		
6	4820	3.68			11625	4.07		

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6	4983	3.70			9050	3.96		
6	5504	3.74			11625	4.07		
6					10688	4.03		
7	12000	4.08	4.08	0.03	27725	4.44	4.32	0.11
7	11800	4.07			18550	4.27		
7	11000	4.04			16750	4.22		
7	11400	4.06			27725	4.44		
7	11400	4.06			18550	4.27		
7	13500	4.13			20800	4.32		
7	12400	4.09			27725	4.44		
7					13863	4.14		

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Annex B

In this Annex are reported data related to experimental campaigns that used alternative sensors for E. coli determination in situ (i.e., devices that are commercial competitor of Fluidion systems), and laboratory analyses of other toxic compounds that were carried out at Peschiera Borromeo WWTP.

Experiences with sensors alternative to the Fluidion devices

CAP Holding has tested different devices for the online monitoring of microbiological water quality. Between 2018 and 2019, two significant experimentations have been performed.

Experiences with Bactosense – Bacmon

BACMON is a detector developed by the Danish company GRUNDFOS. It is a fully automated device for the online monitoring of bacteria in water. Indeed, BACMON can continuously control microbiological parameters employing an automated batch sampling technology. It is based on a patented 3D scanning optics, and it classifies all particles as bacteria or not bacteria by running a digital microscope over a flow cell. Thus, BACMON might be regarded as an automatic and intelligent microscope, which extracts from the detected image several information, including the particles count (i.e., the total number of particles in the sample), and their simple classification (as bacteria/non-bacteria). The absence of the use of reagents and chemicals, the short time needed for the elaboration of the images (results provided in few minutes), and the fully automated operation make this solution not expensive and easy to use. The data are available online (web/app), offline (download), or integrated with SCADA. In the 2018, BACMON was installed at Peschiera Borromeo WWTP before the UV treatment. Experimental tests were planned to find correlations between the particles count operated by BACMON and E. coli concentrations determined by laboratory analysis. However, the expected correlations were not found mainly due to significant fouling issues of BACMON device, which required very frequent cleaning procedures.

BactoSense® is a detector developed by the Swiss company SIGRIST-PHOTOMETER AG. BactoSense® has been tested by CAP during an experimental campaign conducted in collaboration with the producer company and the Department of Civil and Environmental Engineering of the Polytechnic of Milan. BactoSense® is an automatic flow cytometer developed for the determination of total microbial cell count (TCC) and intact cell count (ICC) in water. The whole procedure (sampling, reagents addition, mixing and incubation) is carried out quickly and it is completely automated. The instrument, able to detect more than 99.9% of microbial cells, shows a nominal range of $1 \cdot 10^3$-$2 \cdot 10^6$ cells/ml and has a detection limit of $1 \cdot 10^2$ -$5 \cdot 10^6$ cells/ml. The results, which are available within 20 minutes, can be reviewed and visualized across the measuring period and can be transmitted in analogic or digital format via mA, USB or web interface. Thus, BactoSense® allows a continuous monitoring of the concentration of bacteria in water. CAP Group has tested BactoSense® in a drinking water network during the period May 2019 - October 2019. The device was installed in a water house located in the municipality of Bresso, in the northern area of the Metropolitan City of Milan. The experimentation goal was to find correlations between changes in water flow rates and TCC. Indeed, it was suspected that the release of biofilm from pipes might affect the quality of the delivered water. However, the test was unsuccessful since the BactoSense® devices has never detected TCC. This result was also confirmed by laboratory analyses performed for test control. Thus, BactoSense® was brought to CAP Holding R&D laboratory, where analysis of drinking water samples spiked with known amounts of microorganisms were performed. However, even in this case, a correlation between BactoSense® measurements and laboratory data was not observed.

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Because of this fact, and because BactoSense® device was specifically developed for bacteria monitoring in drinking water, the opportunity to use BactoSense® in wastewater was discarded.

Other possible commercial sensors

A possible alternative to ALERT System by Fluidion that has been used in other European projects such as Hydrousa is the ColiMinder™ technology developed by Vienna Water Monitoring Solutions. The device consists in an automated sampler for the rapid measurement of microbiological contamination. It allows the determination of E.coli, Enterococci and the total activity of bacteria in freshwater and wastewater. ColiMinder™ measures the microbiological contamination through the specific enzymatic activity of target microorganisms. Data can be acquired by remote, and it is possible to set automatic notifications. Moreover, the device is provided with an automatic cleaning and calibration system. ColiMinder™ can perform up to 54 measurements per day, with a response time of 15 minutes. However, as reported by (Angelescu et al., 2019), rapid methods for the direct measurement of enzymatic activity, generally, do not distinguish culturable cells from the inactivated ones. Moreover, these methods are affected by interferences from other types of micro-organisms that have similar enzymes, and from free enzymes present in the sample. It is particularly true in the case of enzymatic techniques without a selective growth step, such as the measurement technique implemented by ColiMinder™.

An additional interesting option is the Colifast ALARM™, an automated online monitoring tool for the detection of E.coli, total coliforms, or thermotolerant coliforms in water. The instrument, which employs a patented Colifast technology, is able to collect 100 ml of samples at a programmed interval, and perform rapid microbial water analysis. The system allows detecting down to 1 cfu/100 ml, and can send results to control rooms/operators via LAN, digital signals, or mobile networks.

ALARM system is based on bacterial growth, group-specific enzyme activity and measured concentrations of a fluorescent product. Specifically, an increase in target bacteria leads to an increment of β-D-glucuronidase, which hydrolyses the growth medium substrate to the fluorescence product that ALARM can finally detect.

Monitoring of other toxic compounds

Analyses of several contaminants of emerging concern (CECs) in wastewater samples collected at Peschiera-Borromeo WWTP were also performed in collaboration with IRSA-CNR and Istituto Mario Negri, which are major research institutes in Italy for water/wastewater treatment and environmental toxicology, respectively.

Originally, two sampling campaigns were scheduled, one in Winter 2019 and one in Spring 2020. The sampling campaign scheduled in Winter 2019 was regularly accomplished. On the contrary, the second sampling campaign was rescheduled for the Summer 2020 due to COVID-19 pandemic.

During the first campaign, monitored CECs included pharmaceuticals, and personal care products (PCPs). Laboratory analyses looked for 42 different molecules in this first sampling campaign. During the second sampling campaign, laboratory analyses will look also for heavy metals, chlorinated organic compounds, pesticides and endocrine disruptors.

The analyses have been performed in wastewater samples collected in both the treatment lines of Peschiera Borromeo WWTP (i.e., Line 1 and Line 2). Data are reported in Table B1 – Table B2

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Table B1: List of sampling points selected at Peschiera Borromeo WWTP for CECs analysis

Line	Sampling point	Reference code
1	Influent	IN PLANT
1	After secondary sedimentation	OUT SED
1	Before PAA disinfection	IN PAA
1	Effluent	OUT PLANT
2	Influent	IN PLANT
2	Before UV disinfection	IN UV
2	Effluent	OUT PLANT

Sampling was performed during two consecutive days during the first sampling campaign. Results of the laboratory analysis for pharmaceutical compounds are reported in Table B2 and Table B3 for Line 1 and Line 2, respectively.

Table B2: Occurrence of pharmaceuticals compounds ion Line 1 of Peschiera Borromeo WWTP during the first sampling campaign

	Concentration in ng/l							
	LINE 1							
	IN PLANT		OUT SED		IN PAA		OUT PLANT	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Ciprofloxacin	277,3	320,9	157,2	184,0	154,9	169,1	155,4	150,8
Clarithromycin	540,1	683,6	393,3	461,3	511,9	500,0	533,9	435,5
Ofloxacin	536,6	554,6	384,2	405,1	428,2	494,1	463,1	461,7
Diclofenac	14345	5255	10493	9460	6881	7172	7859	6006
Ibuprofen	2969,2	2861,9	763,5	997,7	333,7	349,7	443,9	422,3
Ketoprofen	1034,3	1085,6	387,4	555,3	253,9	258,1	348,5	353,5
Naproxen	1089,5	967,3	523,8	571,9	347,9	368,5	381,6	373,1
Irbesartan	685,2	677,9	587,2	664,3	569,4	571,0	625,9	556,9
Valsartan	1368,2	1282,5	628,0	819,4	505,0	459,6	580,4	516,5
Atenolol	1068,9	990,5	502,7	554,9	323,7	316,1	326,0	340,3
Carbamazepine	153,8	155,4	157,2	157,9	168,4	156,4	149,5	144,2
Furosemide	649,1	584,4	285,5	416,3	179,4	192,3	246,5	186,6
Hydrochlorothiazide	726,4	685,3	587,3	615,5	664,7	619,8	653,4	630,0
Ranitidine	20,3	12,2	3,9	7,2	3,3	2,1	4,5	1,4
Bezafibrate	105,5	100,9	61,5	72,7	87,1	86,7	120,1	120,0

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Table B3: Occurrence of pharmaceutical compounds in Line 2 of Peschiera Borromeo WWTP during the first sampling campaign

	Concentration in ng/l					
	LINE 2					
	IN PLANT		IN UV		OUT PLANT	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Ciprofloxacin	309,2	313,0	137,9	153,3	122,6	160,9
Clarithromycin	769,5	641,0	427,5	455,7	558,3	408,6
Ofloxacin	679,5	709,6	351,3	486,7	508,2	492,7
Diclofenac	8970	3883	7162	3320	882	1989
Ibuprofen	2739,6	2551,1	318,3	196,3	214,5	169,3
Ketoprofen	1176,3	1157,6	515,1	445,3	2,0	28,8
Naproxen	1200,2	1008,5	308,5	295,7	268,9	278,7
Irbesartan	808,0	653,8	621,6	744,6	688,9	674,2
Valsartan	1305,8	1204,5	500,3	455,3	443,1	397,7
Atenolol	1047,9	938,1	336,9	312,4	335,3	306,5
Carbamazepine	186,0	159,6	176,5	170,1	163,9	167,7
Furosemide	670,3	593,0	461,2	487,8	421,9	517,4
Hydrochlorothiazide	764,2	682,6	449,9	649,6	532,2	622,8
Ranitidine	19,4	10,9	9,0	8,0	7,4	6,7
Bezafibrate	104,3	91,6	63,3	81,6	54,3	71,0

Results of the laboratory analysis for pharmaceutical compounds for the second campaign are reported in Table B4 and Table B5 for Line 1 and Line 2, respectively. In the last day of sampling campaign in line 2, data are missing due to a problem with the sampler.

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Table B4: Occurrence of pharmaceuticals compounds ion Line 1 of Peschiera Borromeo WWTP during the second sampling campaign

	Concentration in ng/l							
	LINE 1							
	IN PLANT		OUT SED		IN PAA		OUT PLANT	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Ciprofloxacin	235,6	210,4	183,7	169,2	81,2	72,6	115,9	79,0
Clarithromycin	89,8	71,9	60,2	40,6	51,8	36,1	40,5	29,1
Ofloxacin	237,2	215,8	263,2	181,4	175,0	130,2	165,9	128,2
Diclofenac	16028	4615	7948	13207	5867	10691	8578	5636
Ibuprofen	1635,6	1304,0	1011,6	216,4	948,1	172,0	810,2	181,5
Ketoprofen	605,2	495,4	379,3	194,4	171,5	91,7	251,0	78,8
Naproxen	626,5	484,6	474,8	233,3	432,6	185,7	413,1	156,2
Irbesartan	655,0	479,0	669	532	744,0	536,0	787,0	436,0
Valsartan	1012,9	785,2	788,7	490,1	696,8	453,4	677,7	383,8
Atenolol	731,7	559,2	387,5	78,2	312,9	61,7	242,7	56,6
Carbamazepine	170,7	125,3	174,9	140,2	169,2	147,9	162,2	123,3
Furosemide	577,2	418,7	423,5	321,2	343,9	196,4	365,4	190,7
Hydrochlorothiazide	670,6	502,5	574,9	452,6	449,7	340,1	466,1	288,1
Ranitidine	7,8	12,3	4,0	4,0	3,8	2,6	2,4	3,2
Bezafibrate	211,9	392,2	241,1	255,7	380,2	319,4	392,0	282,3

Table B5: Occurrence of pharmaceutical compounds in Line 2 of Peschiera Borromeo WWTP during the second sampling campaign

	Concentration in ng/l					
	LINE 2					
	IN PLANT		IN UV		OUT PLANT	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Ciprofloxacin	213,2	208,7	128,4	116,4	98,0	
Clarithromycin	73,9	121,3	47,8	51,5	44,1	
Ofloxacin	214,5	229,9	177,0	159,8	176,5	
Diclofenac	5159	2976	1860	2765	1156	
Ibuprofen	1339,6	1205,9	19,9	59,7	29,2	
Ketoprofen	659,3	536,6	60,0	149,4	6,7	
Naproxen	723,5	616,5	140,5	190,6	128,6	
Irbesartan	667,0	515,0	923	599	792,0	
Valsartan	888,7	888,2	293,2	343,8	264,2	
Atenolol	695,4	694,4	75,4	107,9	81,2	
Carbamazepine	214,8	181,1	181,8	148,0	177,8	
Furosemide	620,7	491,4	507,3	407,5	332,3	
Hydrochlorothiazide	663,7	549,3	590,2	461,1	427,1	
Ranitidine	3,5	4,6	4,0	3,7	1,6	
Bezafibrate	191,4	226,1	59,9	135,8	104,6	

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Obtained results provide important information about the occurrence of pharmaceuticals in wastewater after different treatment units at Peschiera Borromeo WWTP. Particularly:

- Occurrence of pharmaceuticals was similar at all sampling points during the two days of samples collection;
- The most abundant compounds were the anti-Inflammatory substances (i.e., Diclofenac, Ibuprofen, Ketoprofen, Naproxen), with concentration values in the influent of both the treatment lines higher than 1.000 ng/l;
- The target compounds have different chemical structure and behave differently during wastewater treatment;
- Photosensitive compounds (e.g., diclofenac) were better removed in Line 2 due to the presence of the UV disinfection unit.

In Table B6 and Table B7 are reported the analytical results obtained for PCPs in Line 1 and Line 2 of Peschiera-Borromeo WWTP, respectively.

In this case, the conclusions obtained for pharmaceuticals compounds can be extended to PCPs.

Table B6: Occurrence of PCPs in Line 1 of Peschiera Borromeo WWTP during the first sampling campaign

	Concentration in ng/l							
	LINE 1							
	IN PLANT		OUT SED		IN PAA		OUT PLANT	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
PBSA	586,0	596,4	566,7	635,1	686,6	631,6	585,6	531,0
Benzophenone- 4	502,9	476,5	506,8	535,0	208,8	160,6	221,7	197,5
Triclosan	113,4	102,4	17,5	27,6	16,6	15,8	24,1	14,6

Table B7: Occurrence of PCPs in Line 2 of Peschiera Borromeo WWTP during the first sampling campaign

	Concentration in ng/l					
	LINE 2					
	IN PLANT		IN UV		OUT PLANT	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
PBSA	620,1	541,6	514,3	597,8	574,8	571,4
Benzophenone- 4	458,8	396,9	265,2	568,0	341,9	327,0
Triclosan	97,1	81,1	17,9	18,2	10,4	13,8

In Table B8 and Table B9 are reported the analytical results obtained during the second sampling campaign, for PCPs in Line 1 and Line 2 of Peschiera-Borromeo WWTP, respectively. In the last day of sampling campaign in line 2, data are missing due to a problem with the sampler.

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Table B8: Occurrence of PCPs in Line 1 of Peschiera Borromeo WWTP during the second sampling campaign

	Concentration in ng/L							
	LINE 1							
	IN PLANT		OUT SED		IN PAA		OUT PLANT	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
PBSA	391,2	293,7	494,3	308,5	425,5	316,3	468,0	261,3
Benzophenone- 4	256,8	194,4	276,5	181,2	196,4	162,3	199,0	127,3
Triclosan	43,4	45,0	9,8	11,4	14,4	10,9	10,7	9,5

Table B9: Occurrence of PCPs in Line 2 of Peschiera Borromeo WWTP during the second sampling campaign

	Concentration in ng/l					
	LINE 2					
	IN PLANT		IN UV		OUT PLANT	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
PBSA	341,3	265,2	346,3	249,9	304,7	
Benzophenone- 4	204,8	161,9	162,7	138,6	153,8	
Triclosan	42,6	33,0	7,9	7,7	4,2	

In this case, the conclusions obtained for pharmaceuticals compounds can be extended to PCPs.

Cited literature in Annex B

Angelescu, D. E., Huynh, V., Hausot, A., Yalkin, G., Plet, V., Mouchel, J. M., Guérin-Rechdaoui, S., Azimi, S., & Rocher, V. (2019). Autonomous system for rapid field quantification of Escherichia coli in surface waters. Journal of Applied Microbiology, 126(1), 332–343. https://doi.org/10.1111/jam.14066

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Annex C

Mathematical description of Hotelling's T-square Method

In the mathematical description, it is assumed that the input environment contains n parameters and m measurements for each parameter. Hence, the input matrix X has $n \times m$ components. Similarly, the feature environment can be represented by a $n \times m$ matrix, i.e. $Y_{m\times n}$. The transformation can be done using a whitening or sphering transformation matrix ($Q_{n\times n}$) as follows:

$$\boldsymbol{Y = Q^T.X} \tag{C1}$$

$$where\ Y_{(n\times m)} = \begin{pmatrix} Y1 \\ Y2 \\ \dots \\ Yn \end{pmatrix};\ X_{(n\times m)} = \begin{pmatrix} X1 \\ X2 \\ \dots \\ Xn \end{pmatrix};\ {Q^T}_{(n\times n)} = \begin{pmatrix} q11 & q12 & \dots & q1n \\ q21 & q22 & \dots & q2n \\ & & & \\ qn1 & qn2 & \dots & qnn \end{pmatrix}$$

The main aim of PCA is to find transformation matrix components in a way that the new variables have the most discrepancy (represented by variance). The expected value of a vector with a finite number of components ($x_1.x_2.\dots.x_n$) occurring with probabilities ($p_1.p_2.\dots.p_n$) is defined as Eq. (C2):

$$E[X] = \sum_{i=1}^{n} p_i x_i \tag{C2}$$

$$\text{in which: } p_1 + p_2 + \dots + p_n = 1$$

Hence, the expected value is the weighted sum of the x_i components with the probabilities as weights. If all the components are equiprobable (that is $p_1 = p_2 = \dots = p_n$), then the weighted average turns into the simple average. In the case of standard normal distribution, the mean value of data points is zero, so the expected value of inputs is:

$$E[X] = \sum_{i=1}^{n} p_i x_i = 0 \tag{C3}$$

Furthermore, the discrepancy of an optional matrix (e.g. $\boldsymbol{Z}$) can be measured using its standard deviation (σ^2). Simply, it is proved that σ^2 equals to the expected value of ZZ^T where superscript T refers to the transpose of the matrix.

$$\sigma^2 = E[(Z - E[Z])^2] = E[ZZ^T] \tag{C4}$$

PCA seeks to create the most discrepancy in the feature environment, in mathematical expression one is dealing with an optimization problem as follows:

- The optimization problem (maximize the variance of the feature environment): $E[YY^T]$
- Condition #1: the scale of input data must not be changed, so: $\|Q\| = 1$

(C5)

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The variance of the feature environment can be calculated as Eq. (C6):

$$E[YY^T] = E[Q^T X X^T Q] = Q^T E[XX^T] Q$$

Let's assume $R = E[XX^T]$, so: (C6)

$$\varphi(Q) = Q^T R\, Q$$

Since the maximum of the function is located at its extremum points in which the function derivative is zero, the result of the following equation gives the transformation matrix that satisfies the optimization problem:

$$\varphi(Q + \delta Q) = \varphi(Q) \quad \text{(C7)}$$

where δQ refers to a very small added value.

Manipulating Eq. (D7) results in:

$$\delta Q\, R\, Q = 0 \quad \text{(C8)}$$

And, since $\|Q\| = 1$, then $\|Q + \delta Q\| = 1$. This assumption leads to $\delta Q^T Q = 0$

Integration of various parts of Eq. (C8) and considering a constant value such as λ results in the following equation called eigenvalue problem:

$$R\, Q = \Omega Q \quad \text{(C9)}$$

where R (as defined above) is the variance (covariance) of the input environment, Ω is a diagonal matrix whose components are the eigenvalues (λ) of the matrix R, and Q is a matrix that its components are the eigenvectors of R. Hence, calculating the eigenvalues and vectors of the covariance matrix of the input environment will give the components of the transformation matrix.

Following the above-mentioned concepts, the T-squared method will implement a rotation and then a linear mapping to the initial input environment. As shown in Fig. 4 this mapping will transform data from a hyper ellipsoidal space into a hyper-spherical environment.

In the ellipsoidal state, the geometrical position of data points can be defined using the following equation:

$$X^T R^{-1} X = 1 \quad \text{(C10)}$$

In the PCA description, it is proved that this matrix equals the Variance of the input environment $R^{-1} = Q\, \Omega^{-1}\, Q^T$. The T-squared method will exploit a linear mapping to derive the following equation from Eq. (C5).

$$X^T Q\, \Omega^{-1}\, Q^T X = 1 \quad \rightsquigarrow \quad X^T Q\, \Omega^{-\frac{1}{2}}\, \Omega^{-1/2}\, Q^T X = 1 \quad \text{(C11)}$$

$$Z^T Z = 1 \quad \text{(C12)}$$

Comparing the equations D11 & D12 and assuming $Z = (\Omega^{-1/2})\, Q^T X$, it is evident that $\|Z^T Z\| = X.S^{-1}.X^T$ which must be less than a predefined value, in the case of normal distribution it can be set to 1, for normal data points. If the $\|Z^T Z\|$ for a data point exceeds the predefined value, it is an outlier.

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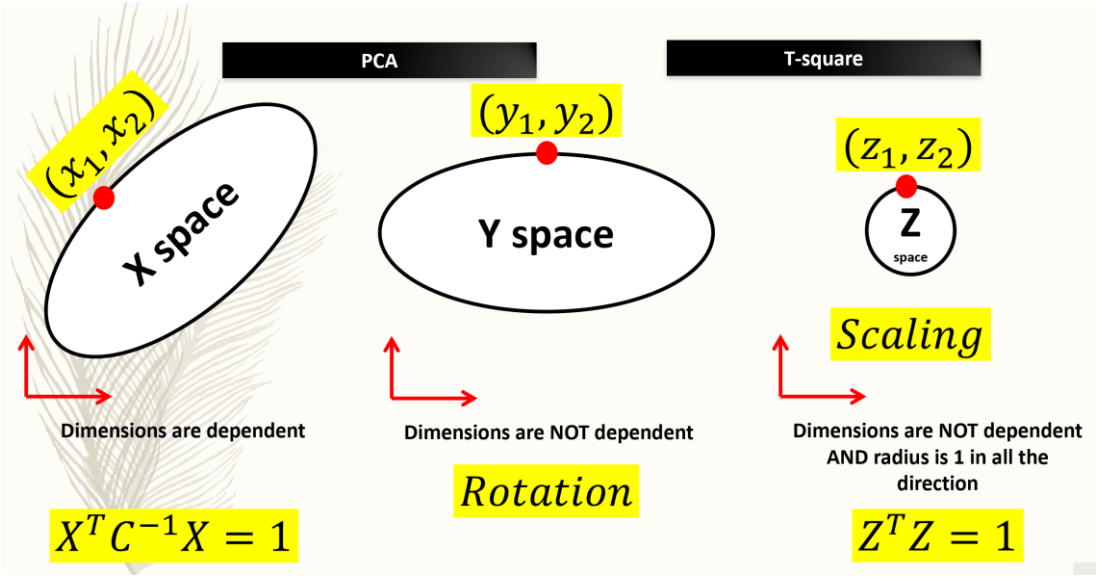

Figure C1. Transformation of the input space into the scaled T-squared space

Statistical indexes

To evaluate the performance of the developed outlier detection models, four statistical parameters including Correlation Coefficient (CC), Root Mean Square Error ($RMSE$), Scatter Index (SI), and $BIAS$ are exploited. The CC measures the strength of the linear relationship between two parameters.

In the current project, these parameters are the daily-averaged prob records and their correspondent lab measurements. The value of the CC varies between -1 to +1 which, respectively, shows the completely negative and positive correlation between the parameters of interest. The $RMSE$ measures the cumulative error of daily-averaged prob records based on their correspondent lab measurements. The more is the $RMSE$ is, the weaker is the predictions of the developed models. The SI indicates the percentage of $RMSE$ concerning the mean of lab measurements. In contrast to $RMSE$ which has the same dimension of the investigated parameter, SI is not affected by the parameters scale since it does not have any dimension. To recognize that the models' predictions are overestimated or underestimated, $BIAS$ can be implemented. The positive values of $BIAS$ refer to the daily-averaged prob measurements overestimation while the negative $BIAS$ stands for their underestimation.

To calculate the accuracy of prob measurements, the statistical parameters such as CC, $RMSE$, SI, and $BIAS$ are calculated for the lab and prob data points.

$$CC = \frac{\sum_{i=1}^{N}(L_i - \overline{L_m})(P_i - \overline{P_m})}{\sqrt{\sum_{i=1}^{N}(L_i - \overline{L_m})^2 \times \sum_{i=1}^{N}(P_i - \overline{P_m})^2}} \quad \text{(C13)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(P_i - L_i)^2}{N}} \quad \text{(C14)}$$

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$$SI = \frac{RMSE}{\overline{L_m}} \times 100 \quad \text{(C15)}$$

$$BIAS = \frac{\sum_{i=1}^{N}(P_i - L_i)}{N} \quad \text{(C16)}$$

Where L_i and P_i denote the daily-averaged prob records and their correspondent lab measurements at i^{th} day, respectively, N is the total number of daily-averaged lab values. $\overline{P_m}$ and $\overline{L_m}$ are mean values of daily-averaged prob records and lab measurements, respectively. It should be noted that:

1- The number of daily-averaged prob records is much more than lab measurements. For instance, in the case of NNO_3, there are 127 lab measurements while the number of daily-averaged prob records is 1050. Hence, in this project, the calculation of statistical indices is done based on the joint available measurements, i.e., the days that are available both in the lab and daily-average prob measurement.

2- Depending on the implemented outlier detection method, the daily-average prob measurement will change. Hence, in the above-mentioned equations P_i and $\overline{P_m}$ are calculated for not-cleaned data, cleaned data by MSAD, MAAD, MMAD, T-square, and integrated method.

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Sensors data analysis

Nitrates – Full prob data (January 2018: June 2021)

There are totally 127 daily-averaged lab and prob measurements among which the error (see Eq. (3. 24)) of 72 daily-averaged prob measurements (around 56.69%) exceed 20%. Moreover, mean prob errors before cleaning is 62.5%.

M-SAD performance

As shown in Figure C1, the number of outliers detected in prob instantaneous measurements do not change sensibly when the window size is larger than 500. However, to determine the optimal window size, the number of daily-averaged measurements whose error exceed 20% (Figure) and prob error reduction (Figure) are of interest. These criteria lead to the selection of window size=325 as the most optimal one.

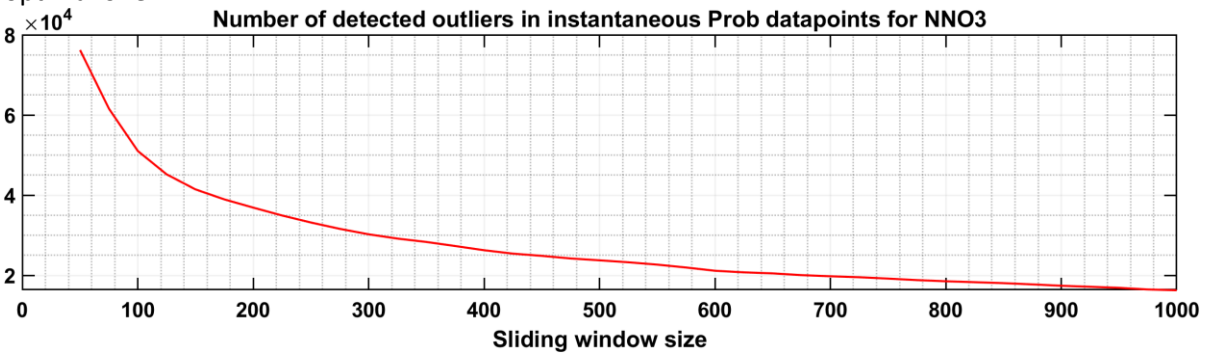

Figure C1: Number of detected outliers V.S. window length in instantaneous Prob datapoints for NNO3

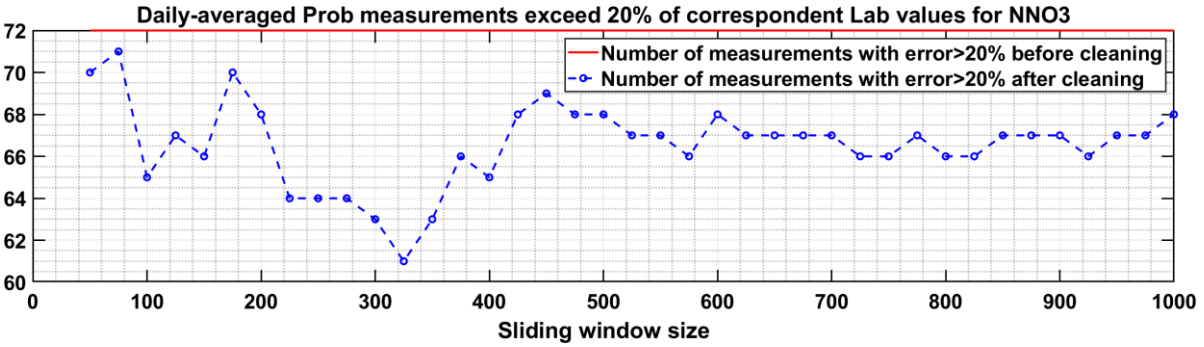

Figure C2. Daily-averaged prob measurements exceed 20% of correspondent Lab values for NNO3

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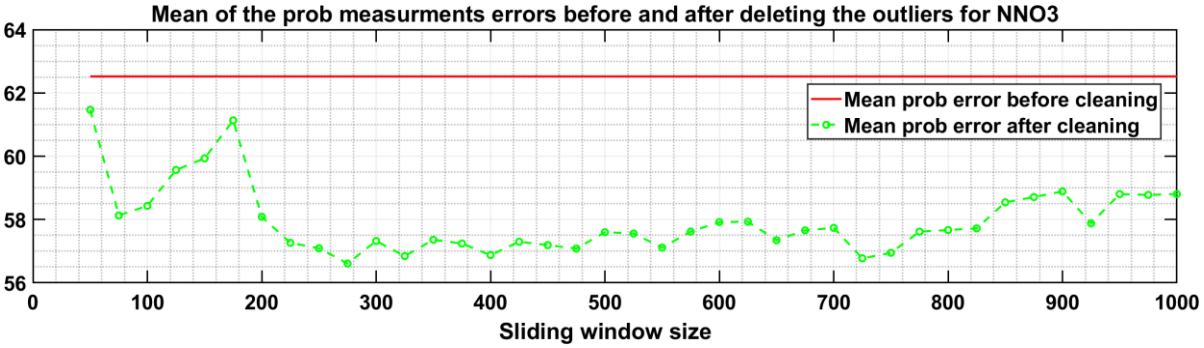

Figure C3: Mean of the errors of prob measurements before and after deleting the outliers for NNO3

Considering window size = 325, the detected outliers out of prob instantaneous measurements are plotted in Figure -C7.

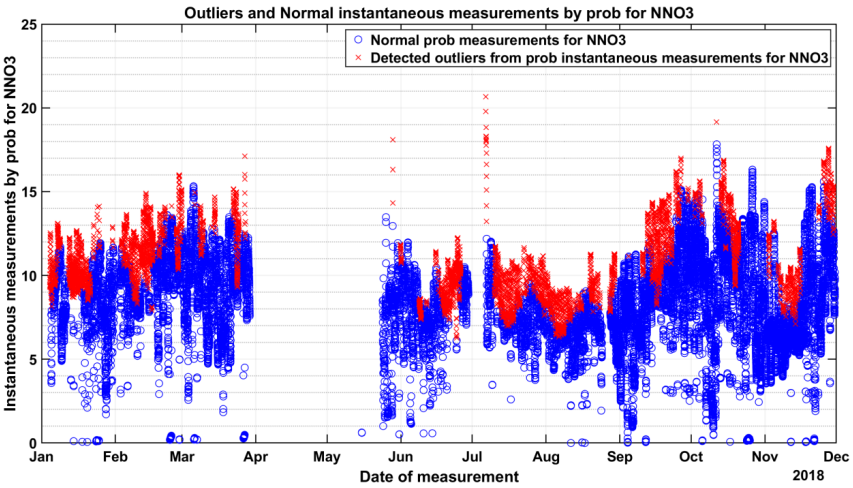

Figure C4. Outliers and Normal instantaneous measurements by prob for NNO3 in 2018

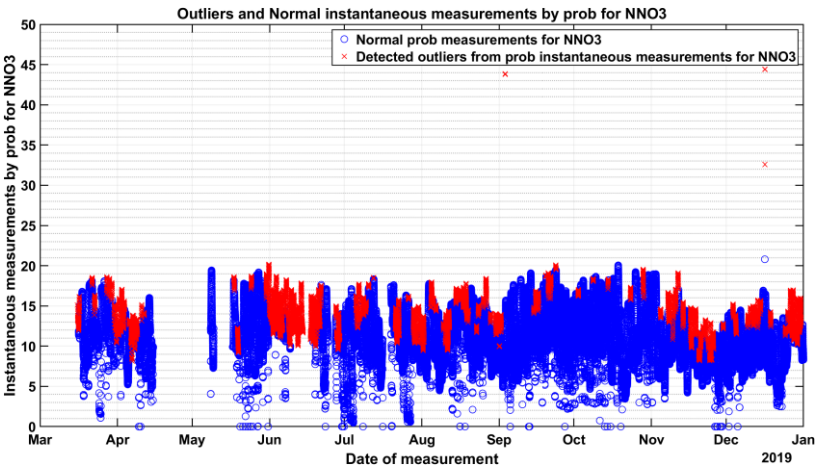

Figure C5. Outliers and Normal instantaneous measurements by prob for NNO3 in 2019

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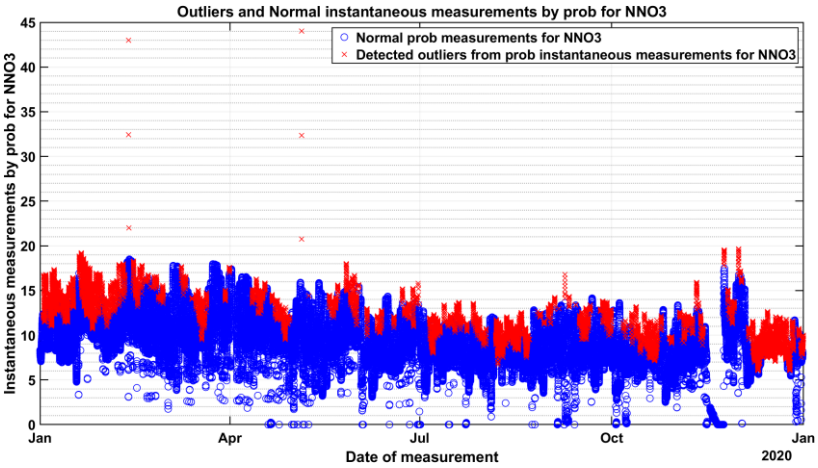

Figure C6. Outliers and Normal instantaneous measurements by prob for NNO3 in 2020

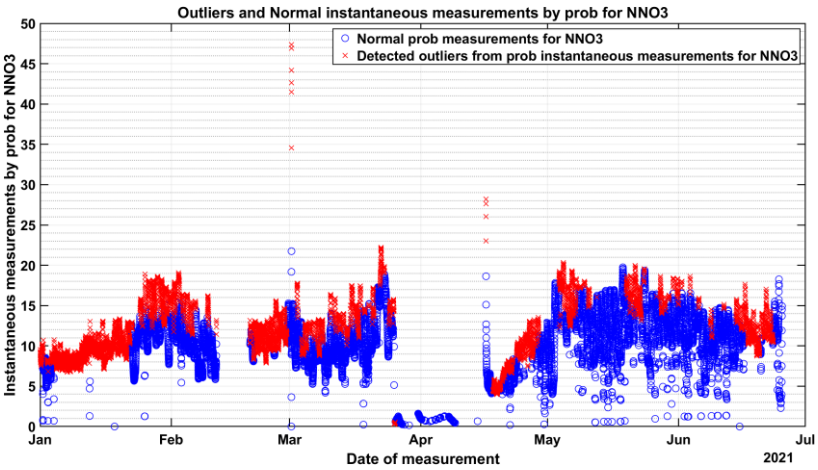

Figure C7. Outliers and Normal instantaneous measurements by prob for NNO3 in 2021

M-AAD performance

As shown in Figure C8, the number of outliers detected in prob instantaneous measurements depends on the window size, i.e., this method is not stable since it does not converge to a specific value as window size varies. Inspection of Figure C10 reveals that this method fails to well capture the outliers of prob measurements. However, the M-AAD performance improves when the window size equals 325.

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Figure C8. Number of detected outliers V.S. window length in instantaneous Prob datapoints for NNO3

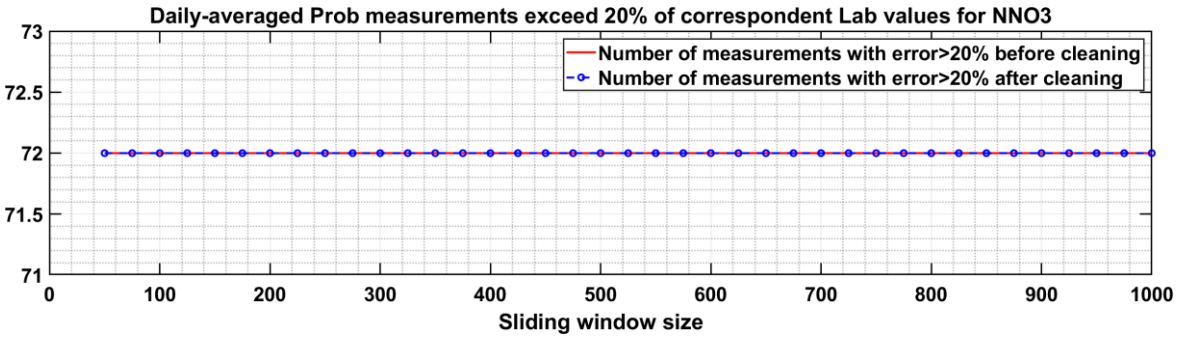

Figure C9. Daily-averaged prob measurements exceed 20% of correspondent Lab values for NNO3

Figure C10. Mean of the errors of prob measurements before and after deleting the outliers for NNO3

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Considering window size = 325, the detected outliers out of prob instantaneous measurements are plotted in Figures C11 - C14.

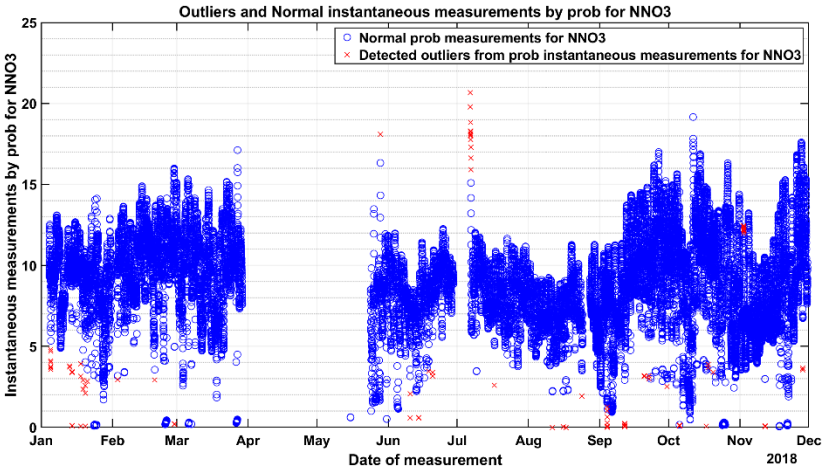

Figure C11. Outliers and Normal instantaneous measurements by prob for NNO3 in 2018: application of M-AAD method

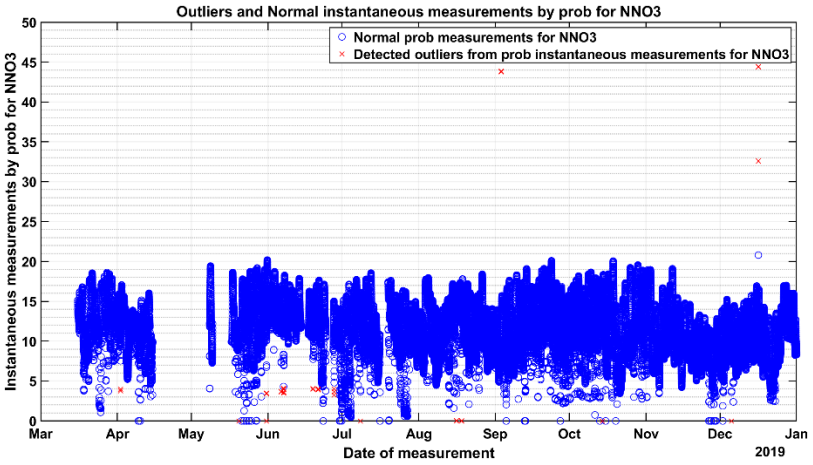

Figure C12: Outliers and Normal instantaneous measurements by prob for NNO3 in 2019: application of M-AAD method

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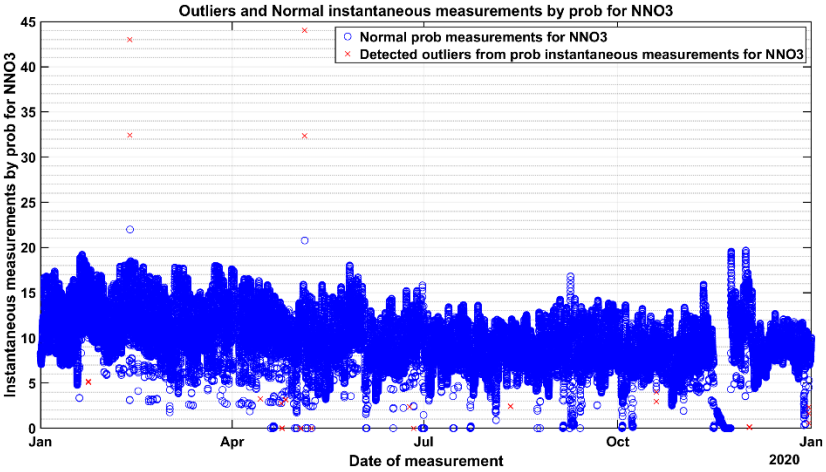

Figure C13: Outliers and Normal instantaneous measurements by prob for NNO3 in 2020; application of M-AAD method

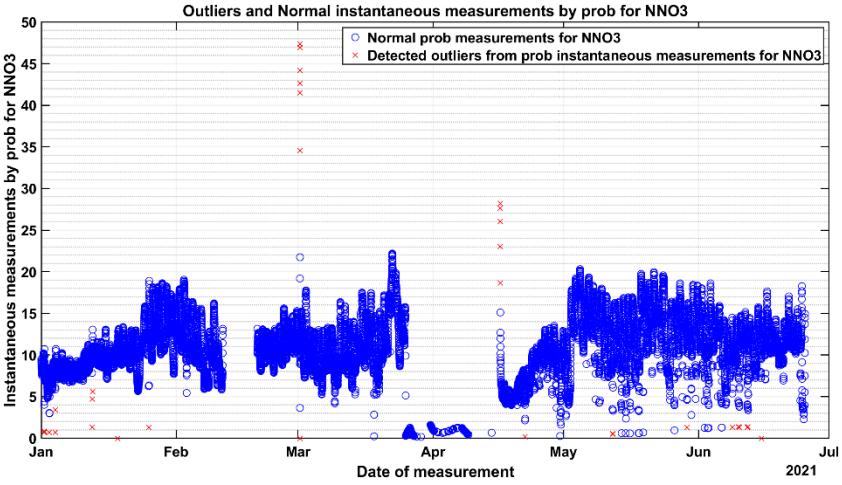

Figure C14: Outliers and Normal instantaneous measurements by prob for NNO3 in 2021; application of M-AAD method

M-MAD performance

Like M-AAD method, the number of outliers detected in prob instantaneous measurements depends on the window size (Figure C15), i.e., this method is not stable since it does not converge to a specific value as window size varies. Inspection of Figures Figure C16 – C17 reveals that this method fails to well capture the outliers of prob measurements.

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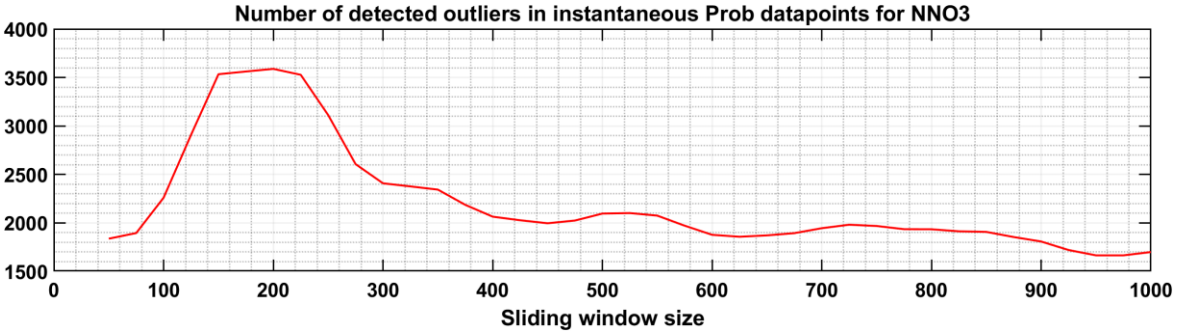

Figure C15. Number of detected outliers V.S. window length in instantaneous Prob datapoints for NNO3

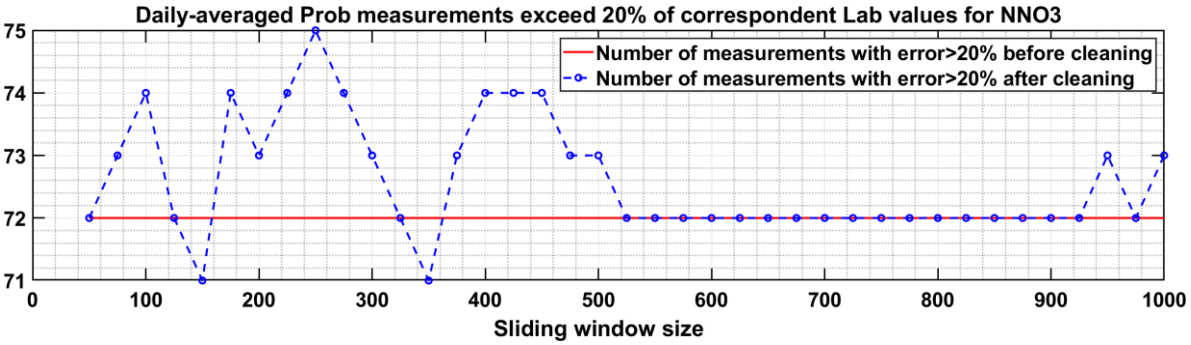

Figure C16. Daily-averaged prob measurements exceed 20% of correspondent Lab values for NNO3

Figure C17. Mean of the errors of prob measurements before and after deleting the outliers for NNO3

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Considering window size = 150, the detected outliers out of prob instantaneous measurements are plotted in Figures C18-C21.

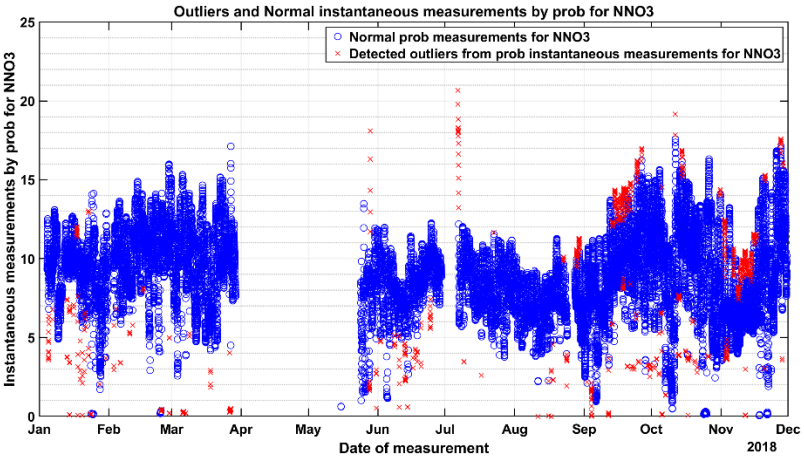

Figure C18: Outliers and Normal instantaneous measurements by prob for NNO3 in 2018: application of M-MAD method

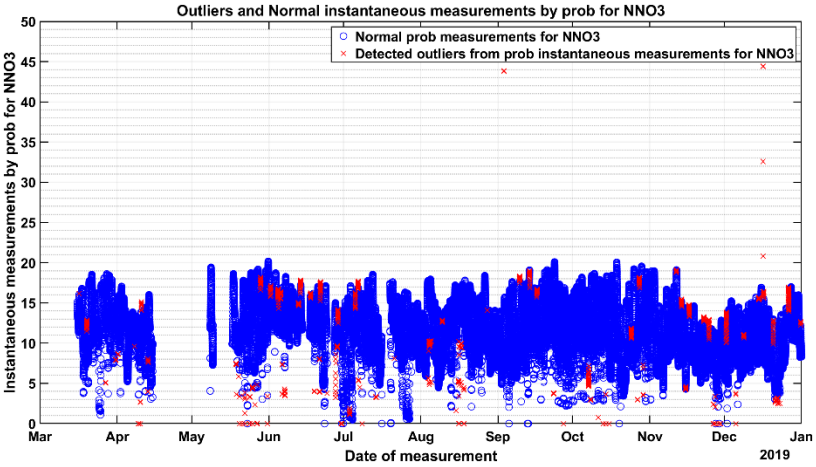

Figure C19: Outliers and Normal instantaneous measurements by prob for NNO3 in 2019: application of M-MAD method

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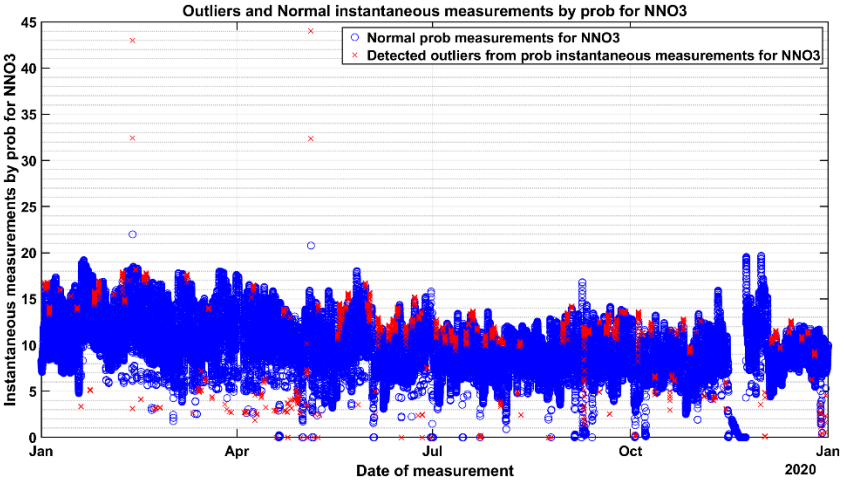

Figure C20. Outliers and Normal instantaneous measurements by prob for NNO3 in 2020; application of M-MAD method

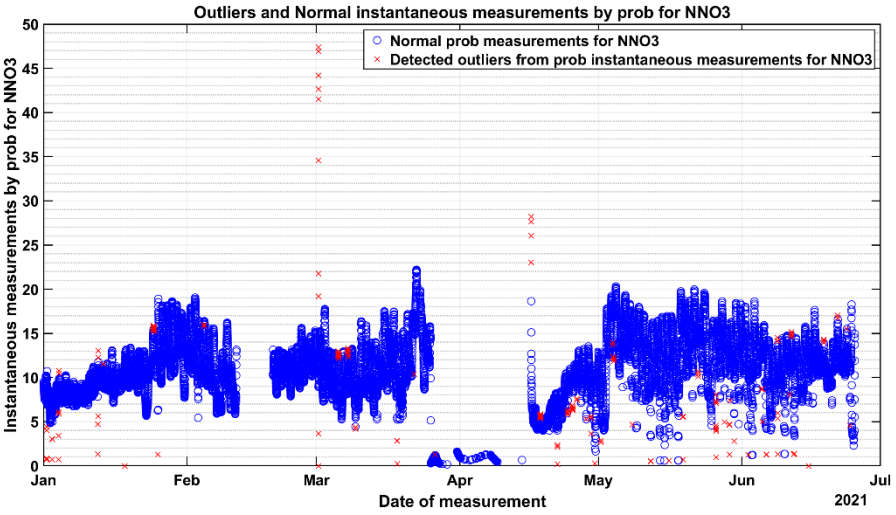

Figure C21. Outliers and Normal instantaneous measurements by prob for NNO3 in 2021; application of M-MAD method

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Hotelling's T-square method

As shown in Figure C22 - **Fehler! Verweisquelle konnte nicht gefunden werden.**C24, the optimal class number is 33 which results in more reduction in mean prob error and amount of data with the error more than 20%. As indicated, implementing T-square method with class number equals to 33 improved the prob measurements accuracy by 1.5% and reduced 1.0% of the datapoints whose error were more than 20%. Although the rate of improvements is not significant in comparison to those of M-SAD, implementation of T-square method can successfully detect the low-values outliers.

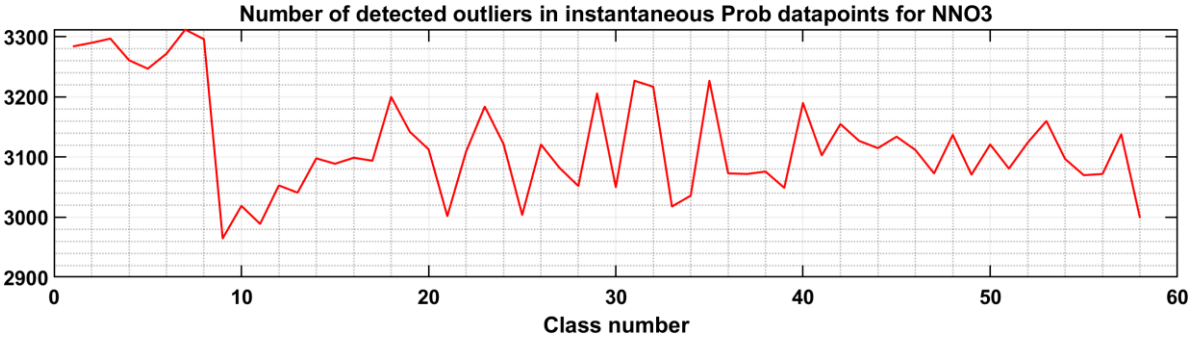

Figure C22. Number of detected outliers V.S. class number in instantaneous Prob datapoints for NNO3

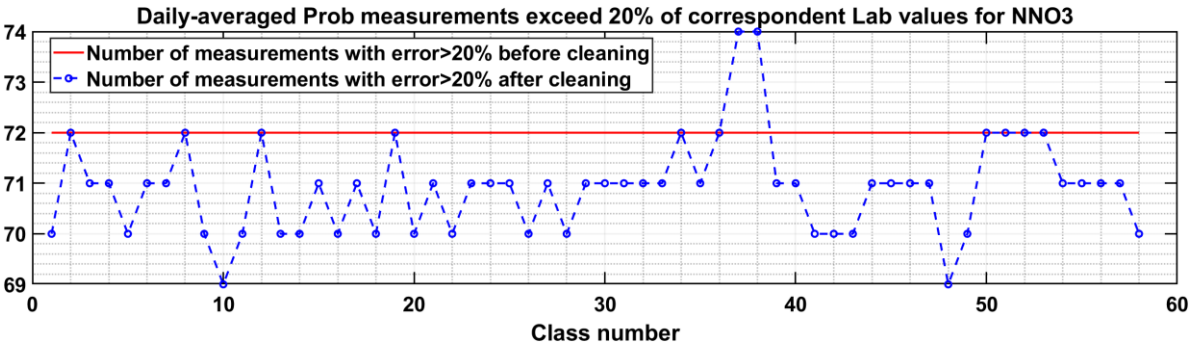

Figure C23. Daily-averaged prob measurements exceed 20% of correspondent Lab values for NNO3

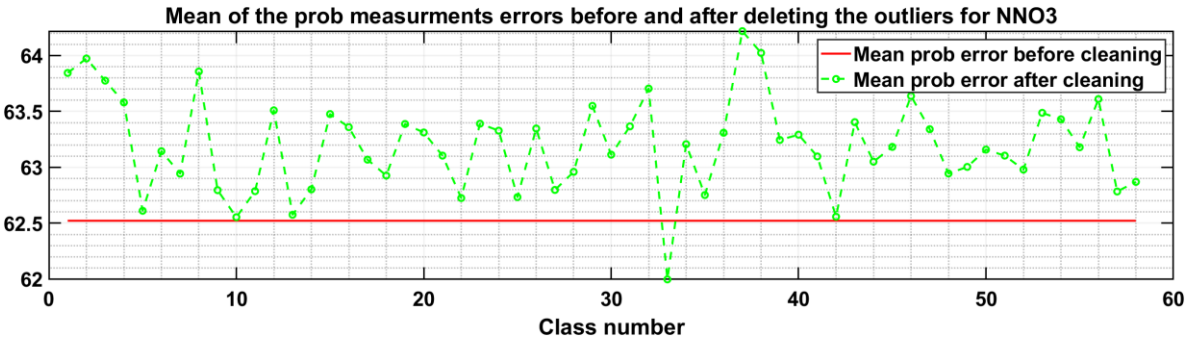

Figure C24. Mean of the errors of prob measurements before and after deleting the outliers for NNO3

Considering class number = 33, the detected outliers out of prob instantaneous measurements are

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plotted in Figures C25Figure – C28.

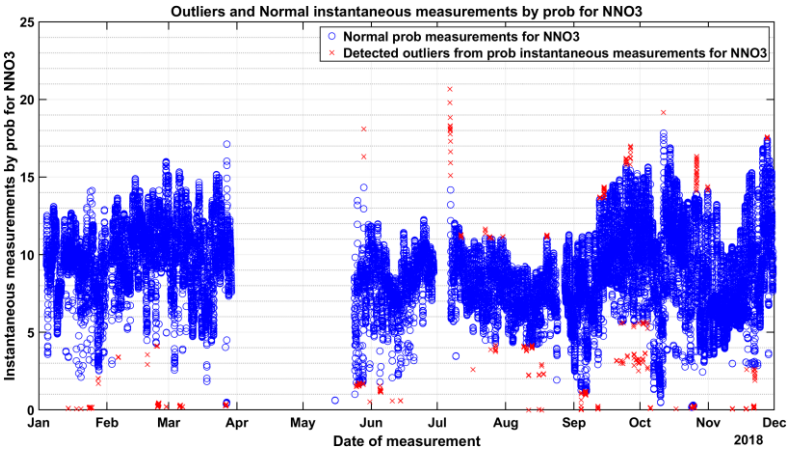

Figure C25. Outliers and Normal instantaneous measurements by prob for NNO3 in 2018

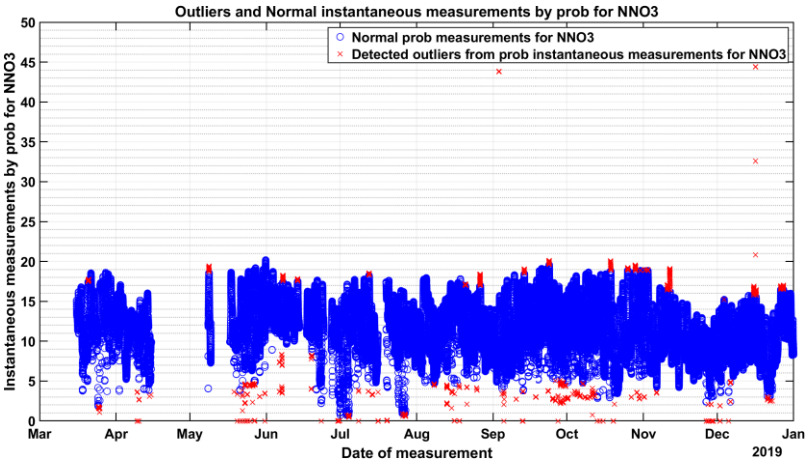

Figure C26. Outliers and Normal instantaneous measurements by prob for NNO3 in 2019

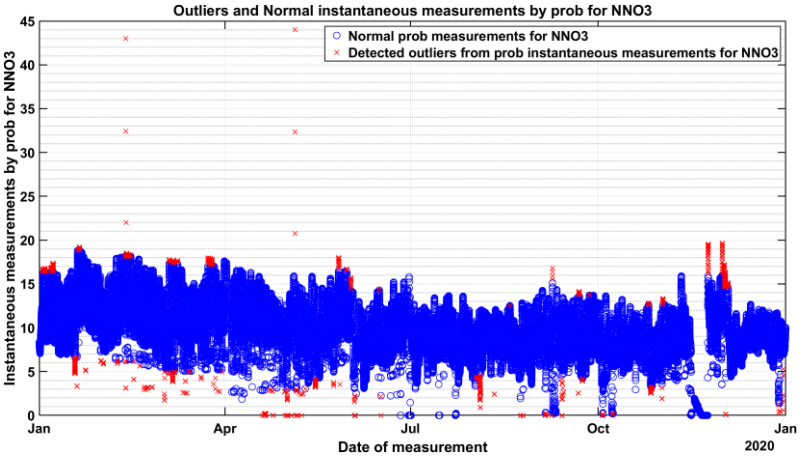

Figure C27: Outliers and Normal instantaneous measurements by prob for NNO3 in 2020

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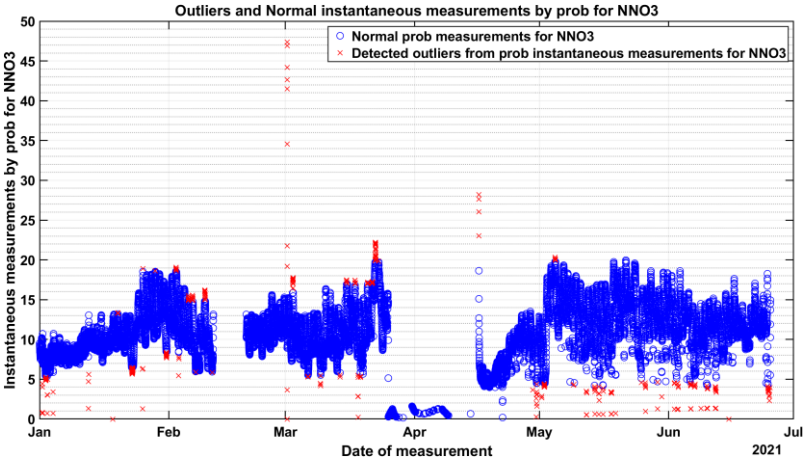

Figure C28. Outliers and Normal instantaneous measurements by prob for NNO3 in 2021

Integrated M-SAD and T-square

As discussed, the M-SAD method outperforms other outlier detection approaches in recognition of large-value outliers. However, T-square method outperforms in detecting low-value outliers. Hence, it is concluded that integration of these methods into one toolbox results in better performance. Accordingly, the integrated M-SAD and T-Square method is implemented into the data when window size is determined as 325 and the class number of T-square method is 33. These values are determined following a trail-error process. A summarized in Table, by implementing integrated method, the number of daily-averaged measurements whose error is more than 20% reduced from 72 to 52 (20.81 % improvement) and mean prob error reduced from 62.52 to 54.77 (12.37% improvement). Figures C29 - C32 illustrate the normal V.S. detected outliers based on the integrated method.

TableC1. Statistical indices of prob measurements before and after cleaning with various method

	No. of data with error > 20%	Rate of exceeded data reduction (%)	Mean prob Error (Eq. 1) (%)	Rate of mean prob error reduction
Before cleaning	72	-	62.52	-
After cleaning using M-SAD	61	15.27	57.21	9.08
After cleaning using T-Square	71	1.0	62.01	1.5
After cleaning using integrated method	57	20.81	54.77	12.37

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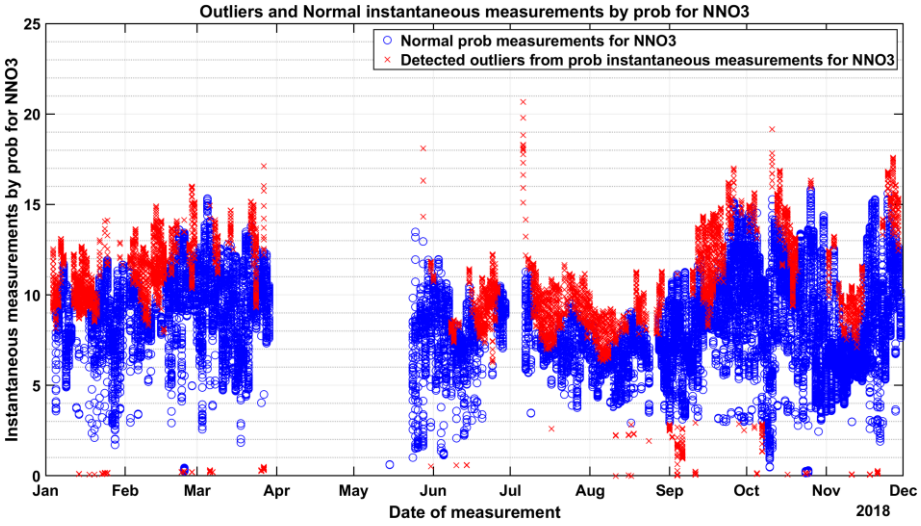

Figure C29: Outliers and Normal instantaneous measurements by prob for NNO3 in 2018

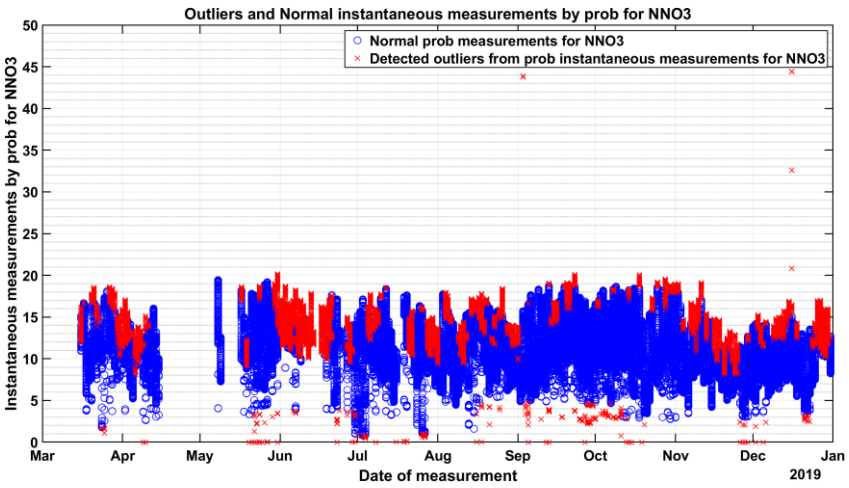

Figure C30: Outliers and Normal instantaneous measurements by prob for NNO3 in 2019

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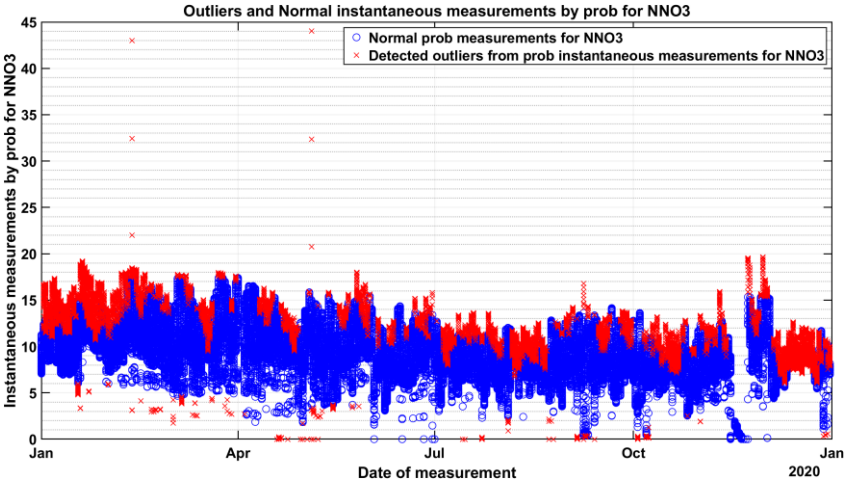

Figure C31: Outliers and Normal instantaneous measurements by prob for NNO3 in 2020

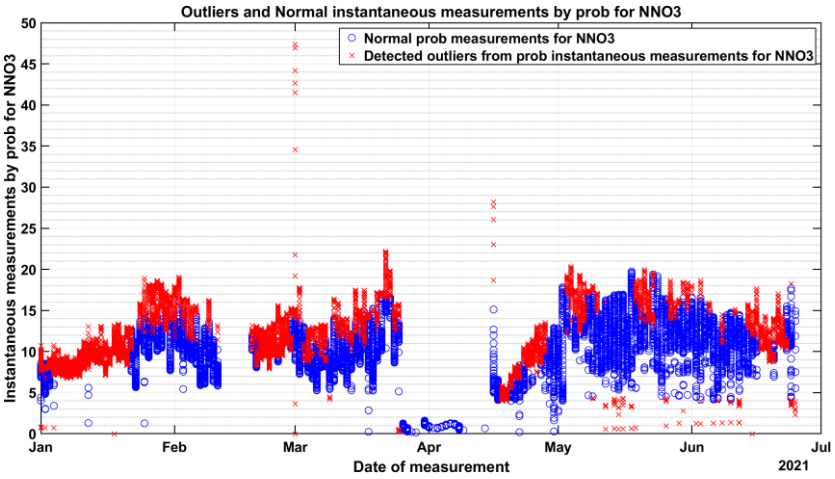

Figure C32: Outliers and Normal instantaneous measurements by prob for NNO3 in 2021

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