Michael Karl Pointl, BSc

Operational behaviour of UV-VIS spectrometer probes exposed to alternating conditions in the Central Storage Tunnel CST in Graz, Austria

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Supervisor:

Ass.-Prof. Dipl.-Ing. Dr.techn. Günter Gruber

Assisting adviser:

Dipl.-Ing. Thomas Franz Hofer, BSc

Institute of Urban Water Management and Landscape Water Engineering

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Contact:
Michael Karl Pointl
michael_pointl@gmx.at

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Abstract

UV-VIS spectrometer probes are the predominant method for in-situ online measurements of pollutant concentrations in urban drainage systems. Operation of these probes in combined sewers and structures such as wastewater storage tunnels poses a particular challenge, as these environments are characterised by complex operating conditions. Depending on a probe's placement and mounting situation, changing operating conditions are the result of probe submersion during periods with higher flow rates caused by storm water run-off and probe dry falling during dry weather periods.

When installed directly inside wastewater storage tunnels, probes are exposed to a continuous sequence of submersion and dry falling periods. These alternating conditions induce potentially negative behaviour of UV-VIS spectrometer probes, leading to poor data quality and considerable maintenance efforts.

In 2014, an inflexible installed water quality monitoring station containing a UV-VIS spectrometer probe was set up in the Central Storage Tunnel (CST) in the city of Graz, Austria.

Since only limited experience in the handling of UV-VIS spectrometer probes in storage tunnels under the aforementioned operating conditions was available so far, a series of laboratory and field tests were conducted for this thesis, with the goal of gaining insight in the processes in the CST and their effects on the reliability of data generated by in-line probes.

Based on an implemented concept for visual analysis of time series characteristic patterns indicating negative probe behaviour were identified and linked to their sources. Findings of this process were consolidated in a set of measures, including modifications of the existing monitoring installation in the CST. Changes to the current equipment installation and configuration are proposed and an algorithm for the implementation of on-demand maintenance of UV-VIS spectrometer probes in the CST is outlined.

The goal of implementing the proposed measures is to reach an optimal relation between high data quality and minimum maintenance efforts. Thereby, the operation and maintenance costs for the operator can be decreased and the safety of staff members is increased.

Kurzfassung

UV-VIS Spektrometersonden sind heute die bevorzugte Technologie zur Online-Bestimmung von Schmutzstoffkonzentrationen in Entwässerungssystemen. Die Verwendung dieser Sonden in der Mischkanalisation und Bauwerken wie Speicherkanälen stellt aufgrund der komplexen Betriebsbedingungen eine besondere Herausforderung dar. Die veränderlichen Betriebsbedingungen resultieren abhängig von der Einbausituation der Sonden in permanentem Abwasserkontakt im Mischwasser- oder Regenwasserabfluss während Regenereignissen und einem Trockenfallen der Sonden während Trockenwetterbedingungen.

Die ständige Abfolge von Einstau- und Leerstandsperioden in Speicherkanälen lässt sich in Form von Eintauch- und Trockenperioden als Abfolge von Betriebszuständen auf UV-VIS Spektrometersonden in solchen Bauwerken übertragen. Dieser laufende Wechsel von Betriebszuständen bedingt ein potenziell negatives Verhalten der Sonden, was zu einer Verschlechterung der Datenqualität und gleichzeitig zu hohem Wartungsaufwand führt.

Im Jahr 2014 hat eine Messstation mit einer starr installierten UV-VIS Spektrometersonde im Zentralen Speicher Kanal (ZSK) in der Stadt Graz, Österreich, den Betrieb aufgenommen.

Da bislang nur begrenzte Erfahrungen mit dem Einsatz solcher Sonden in Speicherkanälen unter den eingangs beschriebenen Betriebsbedingungen vorlagen, sind im Rahmen der vorliegenden Arbeit eine Reihe von Labor- und Feldversuchen durchgeführt worden, um die Prozesse innerhalb des ZSK und deren Konsequenzen für die Zuverlässigkeit von UV-VIS Spektrometersonden nachbilden und erfassen zu können.

Basierend auf einer visuellen Auswertung der generierten Zeitreihen sind charakteristische Muster, die auf negatives Verhalten der Sonden schließen lassen, identifiziert und möglichen Ursachen zugeordnet worden. Die Erkenntnisse aus der Analyse der Daten anhand eines eigens erstellten Konzepts sind in einem Set von Maßnahmen zur Adaptierung der Messstation im ZSK gebündelt worden. Daneben ist ein Algorithmus zur Implementierung zustandsbasierter Wartung für UV-VIS Spektrometersonden im ZSK entwickelt worden.

Ziel der Umsetzung der erarbeiteten Maßnahmen ist das Sicherstellen einer möglichst hohen Datenqualität bei minimalem Wartungsaufwand. Dabei sollen die Betriebskosten reduziert und die Sicherheit des Betriebspersonals erhöht werden.

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List of Abbreviations

AIR	Ambient air in the reactor or sewer, characterised by high humidity
AP	Analytic programme
APCS	Automatic probe cleaning settings
BOD	Biochemical oxygen demand
BOD_5	Biochemical oxygen demand after 5 days
CA	Compressed air
CH	Storage chamber
CHG	Charging (filling) of the reactor
COD	Chemical oxygen demand
CODf	Membrane filtered chemical oxygen demand
CR	Control room or control cabinet
CS	Control structure
CSO	Combined sewer overflow
CST	Central Storage Tunnel Graz, Austria
CV	Check valve installed for automatic probe cleaning
CWS	Combined wastewater substitute
CWW	Combined wastewater
DIS	Discharging (emptying) of the reactor
DO	Dissolved oxygen
DOC	Dissolved organic carbon
EC	Electric conductivity
FT	Field trial
h	Water level, height
IC	Intensive manual probe cleaning
ID	Inner diameter
IMM	Immersion reactor, installed probes are only partially submersed
INS	Installation of additional equipment (period of manipulation for equipment in place or for shared control units or data loggers)
L	Low
M	Medium
MAN	Manipulation (of a single probe or the entire system)
MO	Manual operation (e.g. of a hand valve)
MS	Magnetic stirrer

NC	No manual probe cleaning
NFD	No feasible data (probe or system currently not or not yet installed)
NO_3-N	Nitrate-nitrogen
NV	No check valve installed for automatic probe cleaning
OD	Outer diameter
OV	Overflow channel
P	Pressure
PA	Polyamide
PRI	Primary probes, category assigned to spectrometer probes
PU	Polyurethane
PVC	Polyvinyl chloride
RA	Reactor aeration
REP	Repair works
RM	Removal of material (e.g. debris, hygiene products) from probes (usually in combination with manipulation)
RPL	Replacement of wear parts, sensor caps or cartridges
SCADA	Supervisory control and data acquisition
SEC	Secondary probes, probe category assigned to additional (non-spectrometer) probes and sensors
SER	Equipment service, i.e. discharge of water- or oil separators used for compressed air cleaning
SOC	Special operating conditions (emulation of worst case scenarios, e.g. to force drift development)
STB	Stable operating conditions (no change in volume, no charging or discharging of the reactor)
SUB	Submersion reactor, installed probes are submersed completely
T	Temperature
TC	Timer clock
TOC	Total organic carbon
TSS	Total suspended solids
TW	Tap water
v	Velocity
VI	Visual inspection of installation, mounting system or equipment (no manual cleaning, but system manipulation is possible)
WWTP	Wastewater treatment plant
δ	Symbol, indicating the variation of an operational factor, parameter or setting during a trial

1 Introduction

1.1 Motivation

Continuous water quality monitoring with in-situ probes at high frequencies becomes more and more common in urban drainage systems, leading to large data sets and increasing requirements in equipment and data handling, in particular when considering equipment and measurement uncertainties, which can be sensor and site-specific (Métadier & Bertrand-Krajewski, 2011). For in-situ online monitoring of pollutants in wastewater and combined wastewater, ultraviolet-visible (*UV-VIS*) spectrometry is widely used, but little has been reported so far on the suitable application of such probes in urban drainage systems where the probes are not covered with wastewater continuously. In these systems with highly variable hydraulic conditions, the risk of probe fouling and limited access for maintenance pose considerable challenges for placing and operating these probes directly in sewers (Brito et al., 2014, 2015).

In the context of *in-situ* water quality monitoring, meaning monitoring on site, directly in the sewer system, as opposed to *ex-situ* monitoring in a laboratory, the term *fouling* describes the process of the formation of (bio) films, plaque or mineral encrustations on a probe’s sensors as a result of residue and particle accumulation when exposed to a submersion medium. Probe fouling results in inaccurate measurement results. The extent of the resulting distortion of the generated data increases over time, as the plaque on the sensors becomes more pronounced and permanent. To prevent effects of fouling, most available probes for water quality monitoring in sewers have built-in automatic cleaning systems. Nonetheless, regular on-site maintenance by well trained staff in the form of servicing and cleaning of the probes, is inevitable in order to ensure the reliability of the generated data.

At the Institute of Urban Water Management and Landscape Water Engineering at Graz University of Technology (Austria), the installation and operation of online probes have been practiced for more than a decade. At this institution, operation of in-situ water quality monitoring installations covers a wide spectrum of applications in storm water and wastewater. Online probes have been operated under stable, quasi-static conditions on wastewater treatment plants and in bypass installations, as well as in systems with alternating, more dynamic operating conditions, like combined sewers, storm water sewers and special structures, e.g. storage tanks and combined sewer overflows (Gruber et al., 2006; Steger, 2011; Hofer, 2012).

Since May 2016, two monitoring stations have been operated at main discharge points of the municipal sewer network of the city Graz, discharging into river Mur as receiving water body. At both stations, the monitoring equipment is installed in-line and thereby directly exposed to a continuous sequence of alternating operational states. Highly dynamic conditions while immersed in combined wastewater during rainfall are followed by periods of static, dry conditions during dry weather. Test runs of both installations suggested a considerable tendency for fouling and a high risk of clogging of the probes' sensors with hygiene products and other debris. Furthermore, analysis of the data generated during these tests showed very distinctive patterns, indicating interference due to sub-optimal installation and configuration of the equipment. Since organic pollutant loads discharged into the receiving water body are of particular interest, a multi-parameter UV-VIS spectrometer probe is operated at both monitoring stations in addition to a variety of other probes.

This thesis aims to address the influence of placement, mounting system, equipment configuration and equipment maintenance on the operational behaviour of UV-VIS spectrometer probes exposed to alternating submersion conditions, with a focus on the specific monitoring installation in the *Central Storage Tunnel CST* in Graz.

The first goal is to optimise the operation of UV-VIS spectrometer probes and their coordination with additional equipment under the aforementioned conditions to increase the reliability of measurement data. The second goal is to determine the fouling behaviour of UV-VIS spectrometer probes and to gain insight in the permanence of encrustations on the optical measurement windows of these probes when exposed to alternating submersion and dry periods. If possible, the effects should be described to a degree were maintenance planning based on an evaluation of characteristics in the generated time series is possible. Ideally, the sources of both, positive and negative behaviour for UV-VIS spectrometer probes, should be pinpointed in order to adapt the existing monitoring installation in the CST. It is aspired to reach optimality between high data quality and little maintenance efforts by reinforcing the first and reducing the latter.

1.2 The Central Storage Tunnel in the city of Graz, Austria

The municipal sewer network of the Austrian city of Graz has an approximate length of 850 kilometres, 70 percent of which are combined sewers, 30 percent are realised as separate sewers. The wastewater of the city is treated in the wastewater treatment plant (*WWTP*) Graz, which is designed for domestic and industrial wastewater purification of 500 000 population equivalents. WWTP Graz is located in the municipality Gössendorf, south of the city of Graz. In order to avoid hydraulic overload of the WWTP from extended combined wastewater flows during wet weather conditions caused by storm events, 89 combined sewer overflows, 38 of which discharge into the river Mur directly, as well as a retention volume of 32 000 m³ are integrated in the sewer system (Holding Graz Services Wasserwirtschaft, 2012).

The first stage of the CST was created in 2012 with the intent of providing additional storage volume during storm events, as the construction of the hydropower plant Gössendorf, in close proximity to WWTP Graz (Figure 1-1), rendered a number of combined sewer overflows hydraulically ineffective. The CST is connected to the treatment plant by a sewer between control structure CS 1 at the end of the storage tunnel and the main collector leading to the WWTP, as well as the storage tanks at WWTP Graz, via control structure CS 0.

The first stage of the CST adds an available storage volume of 25 000 m³ to the retention volume within the sewer system of the city of Graz. An extension of the storage tunnel by a second stage is scheduled to be constructed in the near future, increasing the retention volume of the overall structure to 94 000 m³, providing a total storage volume of 126 000 m³ in the drainage system of the whole city (Golger, 2014; Maier, 2014). A detailed overview and description of control structures CS 1 and CS 0 and the general layout of the CST, exceeding the description and the basic visualisation in in this work is provided in Maier (2014).

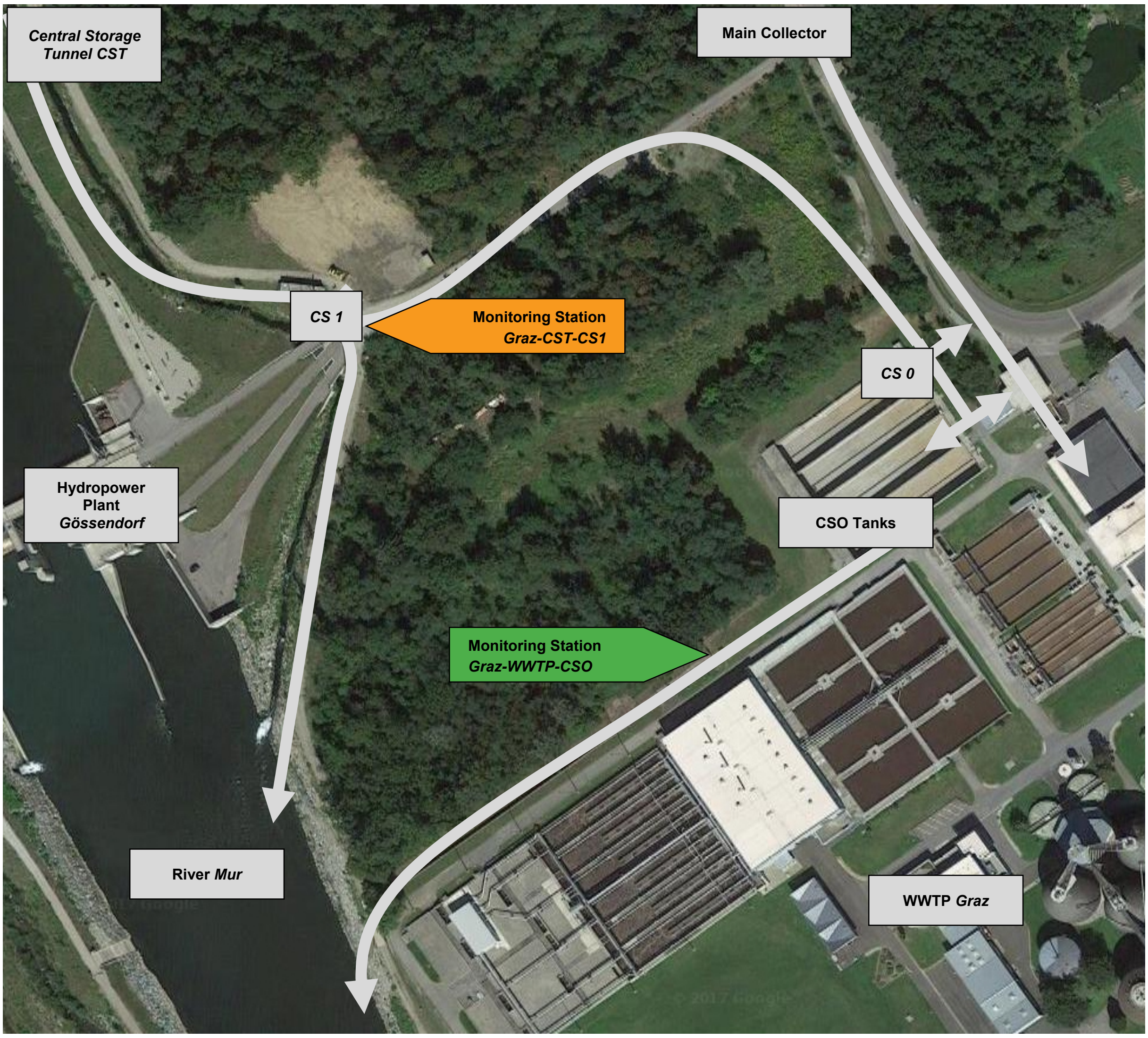


Figure 1-1: Overview of control structures CS 0 and CS 1 of the CST and WWTP Graz (Image: DigitalGlobe, European Space Imaging; Google, 2017; Figure: Hofer (2014), modified)

CS 1 is the control structure at the end of the storage volume of the CST (Figure 1-2). It serves as interface between WWTP Graz and the river Mur. A connection channel at the end of the storage chamber at CS 1 routes stored combined wastewater to the WWTP. Depending on the water level in the chamber during wet weather conditions, movable overflow weirs enable a direct discharge of combined wastewater quantities, to the river Mur by way of an overflow channel if the provided storage volume is exceeded. An additional sluice gate enables the total discharge of the CST into the river Mur by way of the same overflow channel if this gate is open like in Figure 1-2.

Figure 1-2: Sluice gates to WWTP Graz [1] and to the river Mur via the overflow channel [2] and moveable weirs to the overflow channel [3], [4]; storage volume upstream of CS 1 [5] (Photos: Graz University of Technology, 2014)

In June 2014 test operation of the CST started. During this period, a set of in-line online probes, to monitor water levels, flow rates and pollutant concentrations was installed and combined in the so-called monitoring station *Graz-CST-CS1* at the end of control structure CS 1. The monitoring equipment was installed at the end of the storage chamber in CS 1 (Figure 1-3) with the intent of monitoring pollutant concentrations in the stored combined wastewater regardless of the direction of discharge. Thereby, the monitoring equipment of station Graz-CST-CS1 provides data, when the stored volume is routed to WWTP Graz, as well as when it has to be discharged into the river Mur.

Figure 1-3: Probe installation at Graz-CST-CS1 in control structure CS 1 (left, [1]) and front view of the probes (right) (Images: Graz University of Technology, 2014)

While access to the probes of installation Graz-CST-CS1 was possible in 2014, it was limited afterwards due to the CST's pilot testing programme. During this period, a continuous time series was recorded spanning seven months between July 2014 and March 2015. Due to the limited access, this data set is characterised by only little available metadata (e.g. manipulations of the installation, changes to the equipment configuration or cleaning of the probes). Nonetheless, three key constraints of monitoring station Graz-CST-CS1 as depicted in Figure 1-3 were identified:

- The vertical installation of the UV-VIS spectrometer probe,
- a high risk of clogging in general and
- a high risk of clogging with hygiene products in particular.

In the storage tunnel, probes are exposed to a continuous sequence of alternating operational states. Periods of probe submersion in combined wastewater in the case that combined sewerage is temporarily stored in the CST are followed by dry periods in the ambient air of the structure in the case that the CST is emptied and vice versa (Figure 1-4). The ambient air in control structure CS 1 is characterised by high humidity and a constant draft. In addition to states of submerged and dry conditions, phases of transition during which the water level rises above or sinks below the sensors of in-line probes were also expected to have an impact on the quality of the recorded data.

The maximum duration of storage events and thereby probe submersion periods in the CST can be predicted accurately within a limited range, based on extensive testing during the period of test operation. The duration is limited by the cleaning performance of WWTP Graz and the requirement to avoid decomposition of the combined wastewater in the CST. The targeted maximum storage duration should be less than 24 hours. Nevertheless, experience shows, that in the aftermath of longer precipitation events, discharge durations via the WWTP can increase up to 48 hours due to the additional stress for the treatment plant resulting from the run-off of the precipitation event (Hofer et al., 2015).

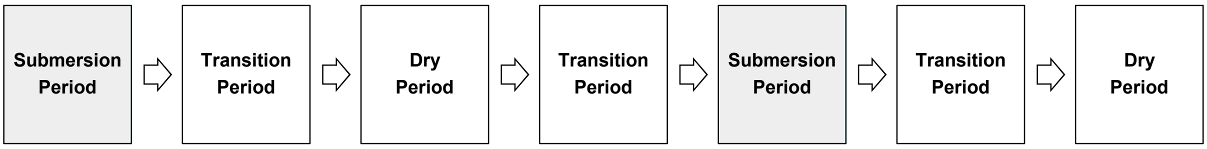


Figure 1-4: Schematic sequence of operational periods in the CST

At the beginning of the testing phase for the CST and the monitoring equipment of Graz-CST-CS1, effects of probe clogging and probe fouling were merely subject of theories rooted in operational experience from other monitoring stations. Sedimentation of mineral and organic wastewater components in the measurement window of the vertically installed UV-VIS spectrometer probe and its influence on probe fouling were subject of discussion and thus of particular interest for this thesis. As the risk of probe clogging became apparent early in the testing period, a prototype of a sheet metal cover was added to the existing installation (Figure 1-5) to reduce and avoid probe clogging.

Figure 1-5: Probe clogging with hygiene products (left), installed sheet metal cover prototype (right) (Images: Graz University of Technology, 2014)

1.3 Functional principle of UV-VIS spectrometer probes

The focus of this thesis lies on the performance of submersible, in-situ, online UV-VIS spectrometer probes exposed to alternating periods of dry operation and submersion in combined wastewater. These probes are used in multiple fields of water quality monitoring. Examples include applications in ground water monitoring, waste and storm water monitoring, as well as process monitoring in wastewater treatment plants (Brito et al., 2014).

The UV-VIS spectrometer probes used for this thesis are of type *spectro::lyser* of the first and second generation, with optical measuring path lengths of 2 mm and 5 mm, manufactured by *s::can Messtechnik GmbH* in Vienna, Austria. These systems have been used for more than a decade at Graz University of Technology for different applications. The probes are characterised by their resilient stainless-steel casing and explosion proofed design, allowing installation directly in the sewer system. They offer an automatic cleaning feature in the form of compressed air flushes, which can be triggered in predefined intervals. Additional information on the probes can be found in the respective manuals (s::can Messtechnik GmbH, 2007, 2011) and in Langergraber et al. (2003). The following description of the functional principle of these probes is based on the description in Hofer (2012).

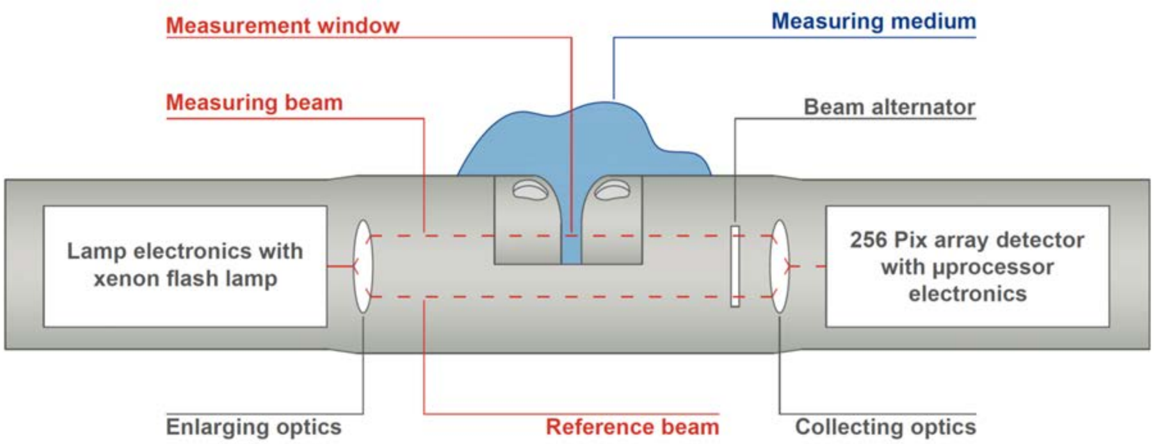


Figure 1-6: Functional principle of a UV-VIS spectrometer probe (Langergraber et al., 2003, modified)

The probe consists of a sender, a xenon lamp, emitting a light beam with a range of wavelengths between 200 nm and 750 nm in a step width of 2.5 nm, including ultraviolet (*UV*) and visible (*VIS*) wavelengths. The emitted light beam is split in a measuring beam, which passes the measuring medium in the measurement window - the optical measuring path - and a reference beam, travelling in a reference medium within the probe. Both beams are targeted on a receiver, holding an optical array detector and processing electronics. By sending a light beam through the measurement window and thus the measuring medium, photoactive molecules in the measuring path absorb some of the emitted light, thus reducing the intensity of the beam reaching the detector. The higher the concentration of the medium, the stronger is the decrease in intensity along the measuring path (Figure 1-6). The use of the reference beam allows accounting for interference of the probe on the data, for instance due to aging of the emitting xenon lamp.

Given the step-width in wavelengths, the probe generates a set of 221 absorbance rates over the spectrum with each measurement. This spectrum is referred to as *fingerprint* by the manufacturer. Based on linear correlation between concentration and absorbance, and the fact that absorbance on certain sections of the spectrum can be linked to specific parameters (Figure 1-7), certain concentrations of pollutants and sum parameters are calculated from the fingerprint. This calculation of a parameter is based on a multiplication of the absorbance rates over the relevant section of the light spectrum with weighting factors defined in the *global calibration* stored on the probes, which are then summed up.

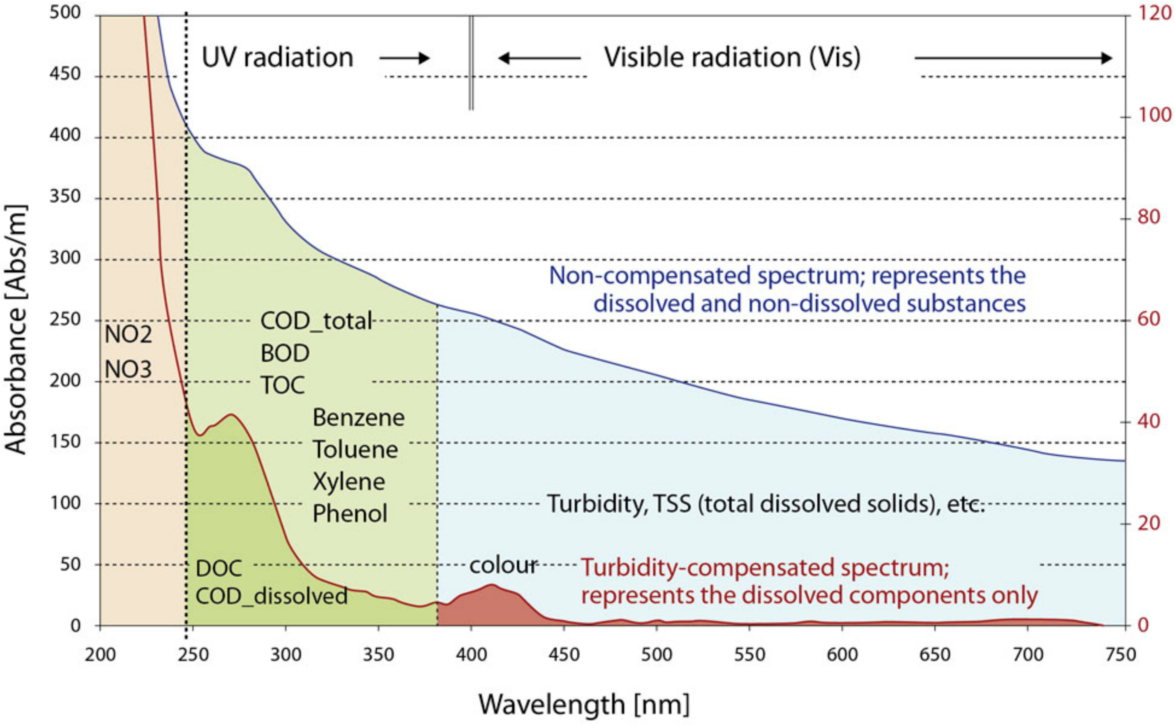


Figure 1-7: Parameter-specific absorption over spectrum of wavelengths (www.s-can.at, accessed 2017-04-04)

The global calibration used for this thesis named *INFLU004V16T* provides equivalent concentrations for the sum parameters total suspended solids *TSS*, chemical oxygen demand *COD*, membrane filtered chemical oxygen demand *CODf*, biochemical oxygen demand *BOD*, total organic carbon *TOC* and dissolved organic carbon *DOC* and a concentration of Nitrate-Nitrogen NO_3-N, as well as temperature results, provided by a separate sensor of the probe. All used spectrometer probes were operated with a distilled water reference.

1.4 Operational behaviour of UV-VIS spectrometer probes

Despite extensive efforts in researching existing literature on the probe-specific operational aspects of water quality monitoring with UV-VIS spectrometer probes exposed to operating conditions similar to the situation in the CST, very little publications on this subject matter were found. This might be rooted in the fact, that the conditions in these systems are highly complex and access to the installed equipment is limited (Hoppe et al., 2009; Brito et al., 2014, 2015).

Different ways of installing spectrometer probes to monitor sewer systems are applied. Options include the use of spatially dynamic installations in form of floating devices (Gruber et al., 2005; Maribas et al., 2008), bypass installations (Gruber et al., 2006) and inflexible installations in the form of mounting to the bottom of the sewer itself (Hoppe et al., 2011). The selection of the mounting system, probe placement and probe configuration are vital to avoid deprecated data due to clogging, fouling or signal noise (Gruber et al., 2006; Maribas et al., 2008). Given the limitations of the probes, like the tendency for fouling without proper maintenance, and the demand for ideal installation and configuration to avoid interference from the equipment on the measured results, the generation of reliable time series might require expert supervision (Hoppe et al., 2009) in general.

Due to the challenging operating conditions, only a small number of publications consider the operation of UV-VIS spectrometer probes in combined wastewater. Information was found in Brito et al. (2014) or in Steger (2011). Other recent studies on this topic are presented in Gruber et al. (2015), Hofer et al. (2015) or Lepot et al. (2016).

In addition to the findings in the aforementioned publications, general requirements for the installation of the utilised UV-VIS spectrometer probes, defined in the respective manuals (s::can Messtechnik GmbH, 2007, 2011), as well as aspects of uncertainty in the operation of such probes (Winkler et al., 2008) and previous experience in their operation in combined sewers (Gruber et al., 2006), were taken into account when identifying the key levels for probe operation in systems with alternating operating conditions represented in Figure 1-8.

Operational experience with these probes described in Gruber et al. (2015), as well as constraints described in additional publications on the aspects of UV-VIS spectrometer probe operation (Bertrand-Krajewski et al., 2007; Hoppe et al., 2009) were considered as well.

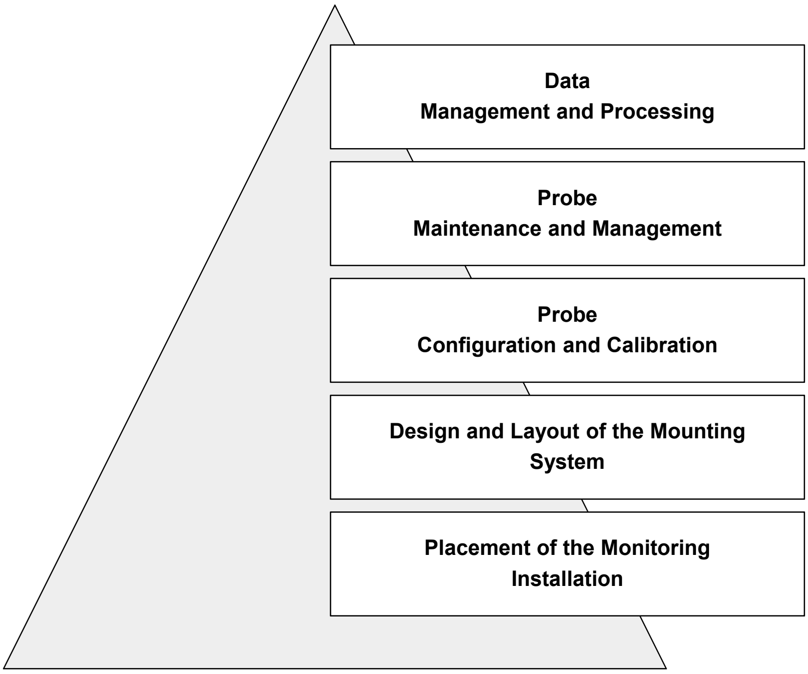


Figure 1-8: Degree of influence on probe behaviour throughout monitoring task

The pyramid in Figure 1-8 shows a series of aspects to consider when designing and configuring a monitoring installation in systems with periodical probe submersion like the CST. The depicted aspects are based on the references above and are supplemented by personal experience with the operation of UV-VIS spectrometer probes.

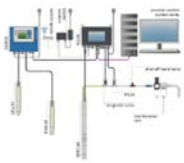
From the base to the top of the pyramid, the degree of influence on the operational behaviour of UV-VIS spectrometer probes and thereby the quality of the generated data decreases. The required technical, personal and cost efforts to implement changes to an existing monitoring system usually increases top-to-bottom. Measures to optimise probe operation should be weighted accordingly and kept in mind when designing an in-line monitoring installation, as well as when developing measures to optimise performance and reliability of existing monitoring systems.

For existing monitoring stations, the levels depicted in Figure 1-8 are analysed top-down to identify problems with the installation based on the existing data. Once the sources for negative probe behaviour are identified, measures can be selected to amplify positive aspects of a monitoring system, while reducing those leading to negative behaviour. At all times, feedback, in particular between the changes at the bottom three levels of the pyramid, has to be considered.

The levels in Figure 1-9 are a bottom-up representation of the pyramid in Figure 1-8, mirroring their degree of influence on data quality of in-line equipment. A number of core aspects for every level is cited.

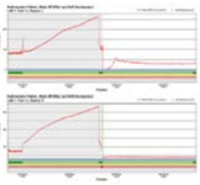
1. Placement of the monitoring installation
The best possible positioning of probes in the operational environment (storage tunnel, combined sewer etc.), as well as their coordination if multiple probes are to be installed and operated simultaneously or in close proximity of each other.

2. Design and layout of the mounting system
All aspects of designing a mount for in-line equipment which has to match requirements of mounted probes as well as the conditions in the operational environment.



3. Probe configuration and calibration
The optimal configuration of measuring interval or automatic probe cleaning settings and timely calibration, if required.

4. Probe maintenance and management
Manual probe cleaning, change of wear parts or following up on error messages. While some of the tasks in this level can only be performed on site, others can be performed via remote access.



5. Data management and data processing
The collection of metadata regarding all relevant aspects of probe installation, configuration and maintenance. Processing and structuring of the data for long-term use and analysis.

Figure 1-9: Details on the levels represented in Figure 1-8

1.5 Hypotheses and research questions

In order to optimise the operation of UV-VIS spectrometer probes in the CST, an integrated approach, combining field testing programmes and laboratory experiments, emulating the conditions on site, was devised. This approach is intended to allow the testing of the influence of specific settings and conditions in a closed laboratory environment, before subsequently testing the significance of the resulting findings for on-site operation. Based on the desired optimum for probe operation - combining the highest possible data quality with as little on-site maintenance as possible - three hypotheses and three corresponding research questions were introduced (Figure 1-10).

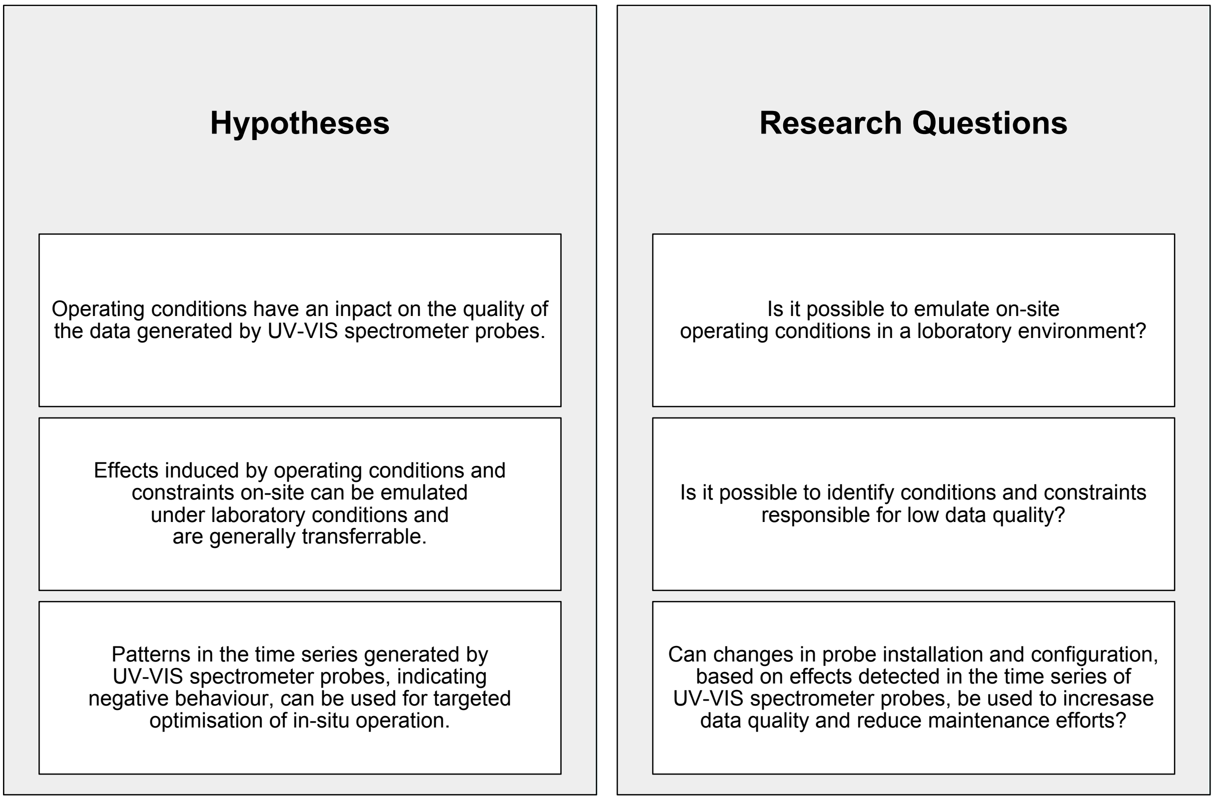


Figure 1-10: Hypotheses and research questions

These hypotheses and research questions were used as a step-by-step approach to compile a list of possible changes to the existing installation at station Graz-CST-CS1. They represent the foundation of the methodology for this work, an experimental approach target at increasing the accuracy and performance of in-line UV-VIS spectrometer probes. Another goal of this approach is the reduction of probe maintenance on site. Ideally the results should be transferrable to other installations with comparable operating conditions.

Subsequently the term *spectrometer* will be used as synonym for *UV-VIS spectrometer*. The term *Institute* is used synonymously with the name of the *Institute of Urban Water Management and Landscape Water Engineering* at Graz University of Technology.

2 Methodology

The layout of the existing installation of Graz-CST-CS1 and findings from the analysis of the data set resulting from the first field testing programme *FIELD 0* were selected as a starting point for the concept and design of laboratory experiments to emulate the constraints and operating conditions inside the CST. The objective was to gain a broader understanding of the key factors responsible for negative behaviour of spectrometer probes exposed to the conditions on site, given the constraints imposed by the characteristics of the environment and the setup of the installation currently in place.

Two stages of laboratory experiments, denoted by *LAB 1* and *LAB 2*, and an additional field testing programme, denoted *FIELD 1* were planned and conducted in order to answer questions regarding influence of spectrometer´s placement, configuration and maintenance on the quality of the generated data.

Visual analysis of time series was used to identify characteristic patterns which indicate possibly negative probe behaviour (e.g. drift phenomena in the time series due to probe fouling). Combined with extensive documentation of metadata and status information over the course of the experiments, the sources for negative probe behaviour could be pinpointed.

Based on the findings of the entire process, a set of changes and modifications to monitoring station Graz-CST-CS1 was compiled. Implementation of the proposed changes is expected to minimise interference from the operational environment, the mounting system and the equipment configuration on the measurement results. Most of the listed changes entail a significant reduction of the risk for probe clogging and a reduction of tendency for probe fouling. Furthermore, a concept for condition-based maintenance planning was developed.

Figure 2-1 highlights the methodology laid out above in a step-by-step manner. Each experimental phase in the laboratory and in the field, is followed by in-depth data analysis, extending the pool of preliminary findings. This process also includes an evaluation of the progress made during an experimental phase in order to implement changes for the next one. Thus, this evaluation serves as decision support system in the planning of the consecutive experiments and trials. A flow chart, providing a more detailed representation of the process on which the methodology of this thesis is based, can be found in Appendix A, section A.0.

This chapter is dedicated to describe the experimental approach for both field trial programmes and both stages of laboratory experiments in the order presented in Figure 2-1. While the evaluation of each phase of the process is detailed in this chapter, the in-depth analysis of identified characteristic patterns takes place in chapter 3.4.1, before a concept to optimise probe operation and probe maintenance in the CST is introduced in chapter 3.4.2.

Figure 2-1: Simplified flow chart of the methodology used for the experimental approach in this thesis

2.1 Identification concept for equipment, chemical analyses and installation positions

Similar to the designation for stages of laboratory experiments (*LAB*) and field testing programmes (*FIELD*), abbreviations and identification numbers have been introduced for probes, control units and chemical analyses.

Identification for specific probes and control units are combinations of capital letters indicating the type of probe and a number referring to the specific probe (e.g. *SPEC.03* for spectrometer probe number 3). A similar approach was chosen for procedures of chemical analysis, which are identified by a combination of lower case letters and a number (e.g. *tss.01* for TSS determination according to analytic procedure number 1).

For every abbreviation or identification (*ID*) additional information and detailed explanations are provided in section A.1 of the appendix.

Operational environments, meaning installation sites in the field and reactors in the laboratory were assigned specific names (e.g. *Reactor 1* or *Graz-CST-CS1*). For every operational environment, a set of site-specific installation levels (e.g. *Level 1*), main positions, denoted by capital letters and auxiliary positions, assigned lower case letters was defined. The particular placement grids for field trial sites and laboratory reactors are described in part in the following chapters and depicted in detail in Appendix A.

This identification concept is aimed at avoiding mistakes in combining probe data and metadata, as well as providing a well-structured data set, the nomenclature of which is homogenous for all trials.

2.2 Influencing factors in the operation of spectrometer probes exposed to alternating conditions

Based on the core aspects and possible influences on the behaviour of spectrometer probes discussed in chapter 1.4, supplemented by data from the first pilot run of station Graz-CST-CS1 in 2014 and 2015, a specific list of constraints and settings, relevant for spectrometer probes in the CST was devised.

The result of this process is a list of influencing *factors* concerning probe placement, installation, configuration and management. The term *factor* itself describes a specific setting (e.g. a change to a single aspect of a probe's automatic cleaning settings or the manual probe cleaning standard employed when maintaining a probe) or a change to a probe's installation (e.g. an increase in inclination or a change of position). The combination of these factors makes up the *configuration* of a probe in a laboratory reactor or a field testing environment. As the thesis progressed, following list of categories was adapted and additional factors were amended, with the goal of covering all reasons for possible negative probe behaviour.

- **Mounting system:** This aspect includes the use of an inflexible (static) installation or a flexible (spatially dynamic) installation (e.g. floats). Regardless of the type of mounting system, in order to operate probes in combined sewer systems properly, sufficient measures to prevent clogging of the probes with debris and hygiene products etc. need to be implemented.

- **Probe placement:** This factor takes the influence of the absolute position of a probe in an operational environment (the position of the mounting system), as well as its position relative to other probes into account.
- **Probe inclination:** Probe inclination can be a factor, depending on operational environment and/or operational requirements defined in the probe's manual. The selection of a suitable probe inclination can help to reduce the interference of the probe on the produced data, especially with automatic compressed air cleaning.
- **Combination of equipment:** Probe selection and combination should be based on site-specific conditions and the monitoring task at hand. While all probes installed in a monitoring station have specific installation requirements, the potential for interference between the probes should be evaluated thoroughly. While certain combinations of in-line probes offer valuable additional insight, other combinations can cause poor data for the entire station.
- **Measuring frequency:** While it might be useful or necessary to push the equipment to the highest possible temporal resolution of monitoring results, the measuring frequency is limited by the storage space and the processing power of the probes, the control units or the used data loggers.
- **Manual probe cleaning concept:** Depending on the installation site, cleaning or maintenance of spectrometer probes can be planned according to a fixed schedule or implemented in a condition-based manner. Insufficient or inadequate manual probe cleaning can induce or advance probe fouling.
- **Manual probe cleaning standard:** All probes should be cleaned to highest standard, as defined in their manuals. During the manual cleaning process, the condition of the whole equipment can be assessed and possible damages can be identified.
- **Manual probe cleaning frequency:** The need for manual probe cleaning depends highly on the operational environment and the wastewater matrix on site. Furthermore, it varies based on the selection of the manual probe cleaning concept.
- **Check valve installation for automatic probe cleaning:** The installation of check valves is targeted at the reduction of interference from the automatic probe cleaning systems of the spectrometer probes on the generated data (e.g. the entrapment of air bubbles in the measurement window).

- **Automatic probe cleaning medium:** While the standard automatic probe cleaning medium for the spectrometer probes used for this thesis is compressed air (s::can Messtechnik GmbH, 2007, 2011), cleaning with tap water was tested additionally in this thesis, to evaluate possible improvements in probe behaviour.
- **Automatic probe cleaning pressure:** For probes with automatic probe cleaning with flushes of a cleaning medium through borings, the pressure can be varied within a certain range to gain the best possible cleaning results.
- **Automatic probe cleaning frequency:** Depending on the operational environment and the submersion medium, the frequency of automatic probe cleaning flushes, as used for spectrometer probes, or wiper blade activations, as used by the other probe types, should be optimised. A limiting factor is the duration of a single flush or wipe, as well as the number of probes connected to a control unit, with regard to the measuring interval.
- **Duration of a single automatic probe cleaning flush:** The duration of an automatic probe cleaning flush was chosen according to the guidelines by the manufacturer (s::can Messtechnik GmbH, 2007, 2011) and the conditions encountered at the existing installation in the CST. Different flush durations were tested during the laboratory trials. Cleaning flush durations can be influenced and limited by the selected measuring interval, depending on the performance of the equipment.
- **Gap or buffer time between automatic cleaning flushes and subsequent measurements:** The gap between an automatic cleaning flush and the triggering of the following measurement, can have negative consequences concerning measurement congruence and time series stability. This is of particular interest with long compressed air lines, where measurements might be triggered while compressed air cleaning is still in progress.

In order to quantify the influence of the listed settings and constraints on the long-term performance of spectrometer probes in systems with alternating submersion conditions, two stages of laboratory experiments were designed to investigate and replicate as many of these factors as possible. A second field testing programme, with a flexible, spatially dynamic probe mount, was targeted at testing additional settings and configurations in an environment with conditions comparable to those of the CST. Table 2-1 provides an overview of the varied subsets of influencing factors for the individual experimental stages and field trials out of the all-encompassing list above. While most of the possible settings of field testing programme FIELD 0, which were predefined by the existing installation at station Graz-CST-CS1 were emulated in the laboratory, some had to be discarded due to safety and hygiene regulations. As for FIELD 1, the majority of possible variations of the factors listed above were predetermined by the existing mounting system. Nevertheless, the combination of all trials in the field and the laboratory provided comprehensive insight in the key influencing factors of the operation of spectrometer probes in systems with alternating submersion conditions.

Table 2-1: Viable influencing factors and possible settings for probes during laboratory and field trials

Variable Operational Constraints and Settings	Possible Implementation for Specific Trial Programme			
	FIELD 0[1)]	LAB 1	LAB 2	FIELD 1
Mounting system	-	-	-	-
Probe placement	-	-	x	-
Probe inclination	-	-	-	-
Combination of equipment	-	-	x	-
Measuring frequency	x	x	x	x
Manual probe cleaning concept	x	x	x	x
Manual probe cleaning standard	x	x	x	x
Manual probe cleaning frequency	-	x	x	x
Check valve installation for automatic probe cleaning	-	x	x	-
Automatic probe cleaning medium	-	x	-	-
Automatic probe cleaning pressure[2)]	x	x	x	x
Automatic probe cleaning frequency	x	x	x	x
Duration of a single automatic probe cleaning process (flush, wiper movement)	x	x	x	x
Gap between automatic cleaning and the subsequent measurement	x	x	x	x

[1)] The modifications listed in column FIELD 0 describe those possible without major changes to the equipment or to the existing mounting system.
[2)] While the automatic probe cleaning pressure can be modified in the laboratory it has to be limited at 2.5 bar due to the reactor design and safety regulations.

2.3 Equipment for laboratory experiments and field testing

With the exception of field testing programme FIELD 0, all probes used for field and laboratory experiments were tested and overhauled by the manufacturer and received firmware updates before the beginning of the first set of laboratory trials. If required, a new reference was stored on the probes and sensors beforehand. In the course of all laboratory experiments and field testing programmes, no further probe calibration or reference change took place to ensure maximum comparability.

To generate time series of the highest possible temporal resolution, in order to capture all potential effects and patterns, control units and data loggers were operated at the highest possible measuring frequency. As far as possible, control units were synchronised via online time servers in the field or a central, offline time server in the laboratory. Systems, which did not have the capability to be synchronised automatically, were timed manually, the offset was documented and timestamps were adjusted subsequently in the course of processing the data.

Probes, control units and data loggers used for this thesis were categorised as *primary* and *secondary* equipment. While spectrometer probes and similar optical water quality probes were considered as *primary probes* (*PRI*), since this thesis focused on their behaviour, all other tested probes and sensors, which were applied to gain further insights in system-specific constraints and their effects on the primary probes, were classified as *secondary probes* (*SEC*). A detailed list of the equipment used for field and laboratory trials can be found in section A.1 of Appendix A.

2.3.1 Primary equipment

Primary probes used for this thesis are *spectro::lyser* probes of the first and second generation and *i::scan* probes for water quality measurements in wastewater, all manufactured by *s::can Messtechnik GmbH*.

Figure 2-2: *spectro::lyser* probe of the second generation (www.s-can.at, accessed 2017-07-22)

In addition to varying generations, probes with different lengths of their optical measuring path, were used for laboratory experiments and field testing, with the objective to gain insight in the effects of these factors on probe accuracy and possible fouling characteristics. The length of the optical measuring path refers to the distance between the emitting and the receiving glass surface in the measurement window of the probes.

Figure 2-3: ***i::scan*** **probe (www.s-can-at, accessed 2017-07-27)**

i::scan probes (Figure 2-3) were tested, since they might present a cheaper alternative to *spectro::lyser* probes for online monitoring in combined wastewater, taking into account that theses sensors can also provide the key sum parameters TSS, COD and CODf.

To accurately monitor pollutant concentrations in combined wastewater, the spectrometer probes require site-specific, local calibrations (Hochedlinger, 2005). As a large variation of procedures and approaches to achieve suitable calibrations exists (Lepot et al., 2016), only globally calibrated spectrometer probes were used for this thesis. Taking into account the fact, that the use of global calibrations does not provide accurate measurements on an absolute scale, the gained results are sufficient to describe probe's behaviour and changes in the operating medium on a qualitative scale. The response time of the probes on rapid changes of the operating conditions is sufficient (Maribas et al., 2008). All used primary probes were operated with the same installed global calibration and with the same distilled water reference stored in the probes throughout all trials, both in the laboratory and in the field.

Even though the time series generated by primary probes are only accurate in a relative sense, but not on an absolute scale, the use of an identical global calibration for all spectrometer probes during all trials and on all installation sites, facilitates the identification of specific behavioural characteristics in the time series, as direct comparison of the gained results is possible. Accordingly, it was assumed that continuous calibration of the probes, while not changing the behaviour of the equipment, might alter or distort characteristics of interest in the time series, making it harder to identify and analyse them for different probes or installation sites. Since extensive chemical analyses took place during laboratory tests, subsequent offline calibration of the time series is possible based on the generated data set. Subsequent offline calibration of this data enables a comparison of characteristic patterns in the time series before and after calibration, potentially providing an additional source of insight in operational aspects of spectrometer probes.

Changes to patterns in the time series due to a change of the distilled water reference stored in the spectrometer probes were not taken into account, as operational experience shows, reference changes are only an issue, if the probe shows implausible data as a result of damage.

For information on primary probes and related control units, stored references and applied global calibrations refer to the corresponding tables in section A.1.2 of Appendix A. The respective section contains detailed information on the used primary equipment. This information is intended to enable the reader to further investigate the benchmarks of installed probes, control units and data loggers.

2.3.2 Secondary equipment

Probes and sensors were classified as secondary probes (*SEC*), if their main purpose was to explain the behaviour of the used primary probes, by documenting the states of the operational environment. The selection of secondary parameters, and thereby secondary probes, is based on the availability of the respective probes and the expected additional insight in the processes and operating states in field testing sites and laboratory reactors. The selection was aided by descriptions in Vanrolleghem & Lee (2003).

While the primary equipment is uniformly designed for in-situ application, most of the secondary probes and control units used are intended for ex-situ use in laboratories exclusively (Figure 2-4). All secondary probes and sensors were, if required, overhauled, serviced and calibrated beforehand and operated with the same calibration throughout all trials. In contrast to the primary probes of the previous section, these probes offer accurate absolute values. Examples for parameters monitored by secondary equipment are water levels and flow rates during field testing, and dissolved oxygen, turbidity and electric conductivity during laboratory experiments.

Tables listing the secondary equipment applied in the field and in the laboratory, are provided in section A.1.3 of Appendix A. These tables include the type, serial number and manufacturer of the sensors, probes, data loggers and control units, thus serving as reference for additional information on measuring principles and performance specifics.

Figure 2-4: Applied control units for secondary probes designed for laboratory use

2.4 Combined wastewater substitute and sample characterisation

2.4.1 Combined wastewater and combined wastewater substitute

Due to the defined periods during which the required monitoring equipment was available, it was not possible to use actual combined wastewater (*CWW*) samples for the conducted laboratory experiments. Thus, a replacement, similar in pollutant concentrations and composition had to be found.

As combined wastewater substitute (*CWS*), grab samples were taken from WWTP Graz, between screening chamber and grit chamber. The samples were taken mainly between 6 a.m. and 8 a.m. Even though this substitute medium lacks in comparison with CWW mineral sediment and larger particles in general, it provides the closest resemblance to combined wastewater, as it would be stored in the CST. While the use of CWS allowed scheduling a laboratory trial programme in a reasonable period of time, it also offered the advantage of lacking debris and hygiene products, which could lead to clogging of the spectrometer probes in a laboratory setup without additional sample preparation.

Minimum CWS sample volumes varying from 15 litres during the first stage of laboratory experiments to approx. 200 litres for stage two of laboratory trials were required to fill the applied reactors. Samples were grabbed manually via telescopic dipper and transported to the laboratory of the Institute immediately afterwards. During the 25-minute-long transportation period, the samples were cooled continuously. All samples were homogenised in combining them in a single container and stirring them manually while filling the reactors. Laboratory reactors were filled manually with a graduated beaker during the first stage of experiments and by means of a pump during the second stage.

2.4.2 Parameters for probe behaviour analysis and sample characterisation

2.4.2.1 Core parameters for sample characterisation and probe behaviour analysis

Concentrations of TSS and COD were used as key parameters for characterising CWS samples in the laboratory and CWW submersion media in the field. Operational experience indicated that spectrometer probes display sufficient levels of accuracy for these two sum parameters, even when operated with global calibrations. For this reason, focus was placed on the time series of these parameters when analysing the behaviour of spectrometer probes. Another advantage lies in the fact, that TSS and COD cover both sections of the measured light spectrum, as TSS-equivalent concentrations are calculated from absorption rates over wavelengths on the visible section and COD-equivalent concentrations mainly over wavelengths on the ultraviolet section. Furthermore, time series of the two parameters were employed as indicators for the success or lack thereof in cleaning and maintaining spectrometer probes, as well as for the detection of possible damages (e.g. condensed water behind the measurement window).

Samples for chemical analysis were taken manually with telescopic dippers in the field and beakers of different sizes in the laboratory. They were taken synchronously with measurements of the monitoring equipment. Thus, each sample is assigned a certain timestamp, allowing an unambiguous integration of results of chemical analysis and probe data, which also provides the basis for subsequent offline calibration of spectrometer probes, if required.

2.4.2.2 Additional parameters for sample characterisation and probe behaviour analysis

While TSS and COD served as core indicator parameters in the characterisation of submersion media and probe behaviour in the laboratory and in the field, additional parameters were analysed chemically. Exceeding the aspects outlined in the previous section, additional parameters were of interest in quantifying the differences between the combined wastewater on site and the substituted medium used in the laboratory.

In total, four different *analytic programmes*, all containing a different set of parameters and determinations were conducted. The extent of the selected analytic programmes was depending on scheduling with the Institute's laboratory, costs of supplies and certain limitations for the amount of sample volume which could be removed from laboratory reactors during a trial. All analytic programmes contained the core sum parameters TSS and COD. All samples taken for chemical analysis had a minimum volume of 250 mL, which was required to ensure proper mechanical homogenisation by means of a dispersing device of type *Ultra-Turrax*, which preceded all analytic determinations. Chemical analyses were either standardised or conducted according to manuals.

In addition to TSS and COD the following parameters were analysed. Their combination depended on the respective analytic programme:

- Membrane filtrated chemical oxygen demand (CODf)
- Biochemical oxygen demand after five days (BOD_5)
- Total organic carbon (TOC)
- Dissolved organic carbon (DOC)
- Nitrate-Nitrogen (NO_3-N)
- Temperature (T)
- Electric conductivity (EC)
- PH-value (PH)

Sections A.1.5 and A.1.6 of Appendix A contain tables detailing the applied analytic methods and procedures as well as the corresponding sample volumes and number of determinations for each parameter within the four analytic programmes.

2.5 Field testing programme at CST control structure CS 1 (FIELD 0)

An initial field testing programme called *FIELD 0* was run between July 2014 and March 2015 to get a first impression of the behaviour of the existing monitoring station in the CST. Additionally, this period was used to identify possible problems in probe placement and probe configuration and to estimate the necessary management efforts to service and maintain the equipment during regular operation. The testing of the monitoring installation on site, as outlined in chapter 1.2 was conducted with a measuring interval of 120 seconds. The existing in-line installation and equipment configuration of station Graz-CST-CS1 is at core of all following optimisation processes. A table with the detailed configuration of the installed primary and secondary probes can be found in section A.3.3.2 of Appendix A.

The goal of FIELD 0 was to understand which modifications to the installation and configuration of spectrometer probes might be necessary to produce high quality data while simultaneously reducing the efforts in maintaining the equipment, considering the difficulties in assessing in-line probes during operation of the CST and the need for trained staff to ensure sufficient and safe maintenance. In addition to attempting to get the most comprehensible idea of the combined wastewater and operating conditions within the chamber of CS 1, the testing programme was also aimed at determining a suitable set of probes or sensors for station Graz-CST-CS1.

Laboratory experiments were designed as a way of predicting possible operational difficulties with the installed monitoring equipment. Based on findings from FIELD 0 and operational experience from similar in-line installations, the following key constraints of the existing on-site layout were identified:

- Intermittent drainage conditions in combined wastewater,
- a targeted duration of storage periods of approximately 24 hours (and an estimated maximum storage period of 48 hours),
- high water level above the probes posing a risk for sedimentation in the measurement window of the installed spectrometer probe,
- the inflexible, vertical installation of the spectrometer probe,
- primary and secondary probes installed at different levels,
- a risk of probe fouling without proper equipment configuration and maintenance and
- a risk of insufficient automatic probe cleaning due to the length of the compressed air lining and a too small compressor for providing the compressed air.

These constraints were the basis for the design of a set of laboratory experiments, emulating operation in the CST as closely as possible.

While the results of field testing programme FIELD 0 which were used for this thesis are limited to the approximately eight months of operation between July 2014 and March 2015, some elements of the monitoring station were operated furthermore without active supervision or maintenance until the beginning of October 2015. Between May and October, a series of defects and technical problems occurred. Thus, only limited fragments of the overall time series for this period could be interpreted, in particular when taking into account the lack of sufficient metadata. Nevertheless, these fragments offer some insight in the fouling characteristics of such probes under intermittent drainage conditions in case of total neglect. The implications for permanent fouling of spectrometer probes are highlighted in chapter 3.4.2.

2.5.1 Equipment placement and configuration of station Graz-CST-CS1 (FIELD 0)

Water quality monitoring equipment in the CST is positioned inside of control structure CS 1 right in front of the connecting sewer to WWTP Graz (Figure 1-1 and Figure 1-2).

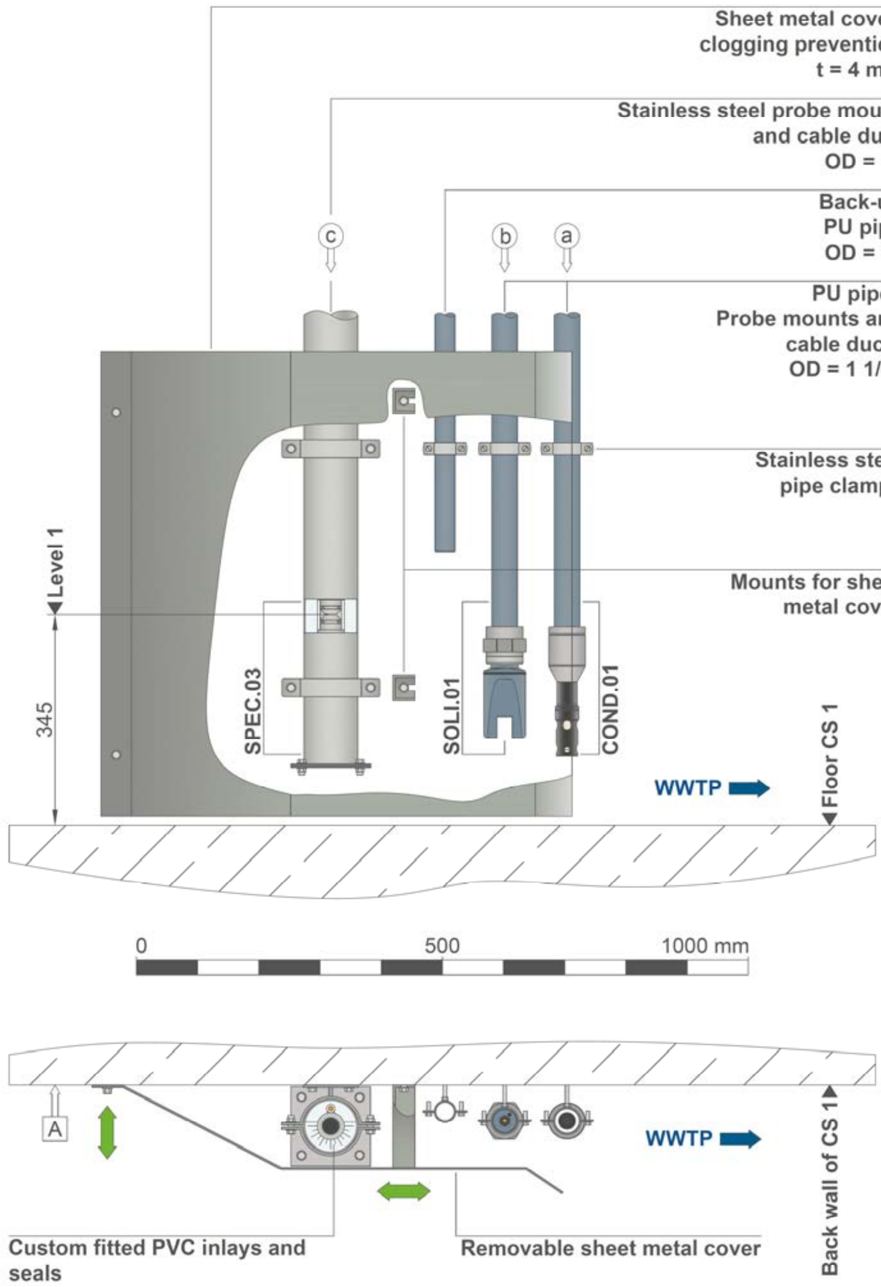


Figure 2-5: Existing water quality monitoring installation Graz-CST-CS1

Due to limited access during the testing period, most of the measurements in Figure 2-5 are approximated, the only definite distance is the 345 mm between the floor of the chamber and the centre of the measurement window of the spectrometer probe. The spectrometer probe is installed vertically and in an inflexible way inside a sealed stainless steel cladding tube, only exposing the area around the measurement window. The additional probes, which are installed at a different, lower, level, are mounted via a combination of polyurethane tubes and fittings.

Figure 2-6: Clogged spectrometer probe (left) before the installation of a sheet metal cover (right) (Images: Graz University of Technology, 2014)

As the risk of clogging became obvious (Figure 2-6, left), a sheet metal cover, made of stainless steel was positioned in front of the in-line equipment (Figure 2-6, right). As a result, clogging of the probes inside the chamber was no longer considered a relevant issue, even though the design and measurements of the installation as a whole were still suspected to be suboptimal when testing programme FIELD 0 started. Additional probes in CS 1 monitor water levels and flow rates in the chamber and in the overflow channel of the structure. They are mounted to the ceiling of the chamber and the overflow channel. Therefore, clogging and fouling of these sensors were no issue with the exception of cobwebs that can negatively influence the ultrasonic water level measurements.

Instead of clearly defined thresholds for submersion of the lower secondary water quality probes and the higher positioned primary probe of installation Graz-CST-CS1, a threshold of a certain bandwidth between 200 mm and 345 mm was used, when reviewing the data and distinguishing between submersion and dry periods. The 200 mm are the approximated water level when submersion of the secondary probes starts, while the 345 mm represent the measured distance between the floor of the chamber and the centre of the measurement window of the spectrometer probe (Figure 2-5).

Power supply and data connection as well as compressed air lining is bundled in cladding tubes for every probe (Figure 2-6, right), leading to the control room of station

Graz-CST-CS1. The length of the cables and compressed air lines is considerable at approximately 10 to 15 metres between the installations in the control room and the individual probes in the chamber. Control units, data loggers and interfaces are installed in an aboveground control room at CS 1 at the end of the CST. The entire equipment is connected to a central control unit (*CC.05* in Figure 2-7) with remote access and a connection to the SCADA system of WWTP Graz. The compressor for automatic probe cleaning is also placed in this control room.

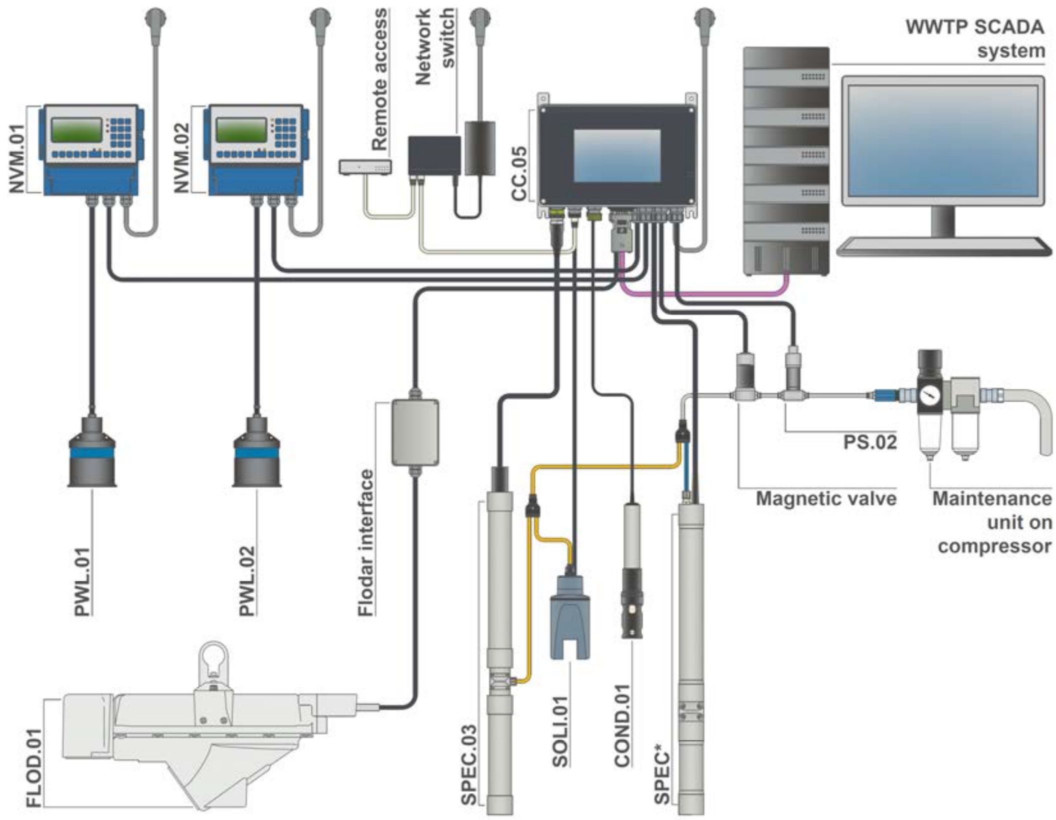


Figure 2-7: Equipment configuration of station Graz-CST-CS1 during FIELD 0

During FIELD 0 another spectrometer probe denoted *SPEC** in Figure 2-7 operated in the overflow channel to the river Mur was connected to control unit CC.05 of station Graz-CST-CS1. While the data produced by this spectrometer probe was not relevant for this thesis, the additional operation of this probe might have led to a lag in the performance of the control unit. Furthermore, as this probe was cleaned with compressed air from the same compressor as probe SPEC.03 in Figure 2-7 via a line of about 15 metres, it might have reduced the pressure supplied to the probes in the chamber of CS 1 significantly. To avoid insufficient cleaning pressure, a more powerful compressor was installed during the testing period.

2.6 Design of laboratory experiments and additional field trials

Based on the identified operating conditions and constraints in the CST and the results of the first field testing programme FIELD 0, laboratory experiments were designed with the main goal of replicating and varying as many of the key constraints as possible for the monitoring equipment of station Graz-CST-CS1.

In accordance with the hypotheses and the research questions introduced in chapter 1.5, a two-step approach was selected for the laboratory experiments. While the first stage (*LAB 1*) was conducted under the premise of testing the possibility of emulating the conditions within the CST and especially of controls structure CS 1 in a laboratory environment, stage two (*LAB 2*) attempted to emulate the conditions on-site as accurately as possible. LAB 2 also took the preliminary findings of LAB 1 into account and offered a number of additional variable factors, while at the same time narrowing the influence of the experimental setup on the data.

As an opportunity to test a spectrometer probe in a spatially flexible installation operated under alternating drainage conditions in an almost identical combined wastewater matrix an extensive field testing programme (*FIELD 1*) was conducted to broaden the scope of this thesis and to substantiate conclusions from the laboratory experiments. FIELD 1 took place in the overflow channel of the CSO tanks at WWTP Graz. The methodology for field and laboratory trials is outlined in Figure 2-1. It shows laboratory experiments and field trial programmes in a sequence targeted at answering the research questions of chapter 1.5, with the goal of validating or refuting the underlying hypotheses.

The overall goal of this process is to design laboratory experiments and field testing programmes to replicate the main constraints and operating conditions in the Central Storage Tunnel in order to minimise negative behaviour of spectrometer probes during submersion and dry periods and to maximise the quality of the generated data, while possibly reducing maintenance efforts on site. Throughout the process in Figure 2-1, the progress in achieving this goal is evaluated. After LAB 1 is completed, the ability to mimic on-site conditions derived from FIELD 0 in the laboratory is assessed. In case the preliminary findings are not satisfying the process is terminated, if they are promising, the limitations of the concept and layout used for LAB 1 are considered for the concept for LAB 2. In a next step, the laboratory trials of LAB 2 are conducted and evaluated. Upon completion of this second stage of experiments, the preliminary findings of all tests up to this point are combined and assessed. If the deduced modifications can be applied directly to the installation in the CST, they will be realised and evaluated. Otherwise, FIELD 1 is conducted to gain a deeper insight in operation under in-situ conditions. The findings of FIELD 1 are included in the overall set of findings and in a proposed list of changes to the existing station Graz-CST-CS1. Progress, problems and findings are documented continuously.

2.7 Two stages of laboratory experiments

A set of laboratory reactors was designed and multiple trials were conducted as the first steps in implementing the methodology of Figure 2-1, in an attempt to answer the three research questions of Figure 1-10.

As monitoring station Graz-CST-CS1 was already installed and operational when work on this thesis started, the experiments were designed to emulate the constraints of this installation. Supplemented by findings based on the data from field testing programme FIELD 0, a first, simple experimental setup was designed, evaluated and followed up by a second set of trials with a more advanced reactor design. The idea was to identify reasons for negative behaviour of vertically installed spectrometer probes in combined wastewater with alternating submersion conditions, as encountered in the CST. Based on the findings of this process, the operation of Graz-CST-CS1 was to be optimised under the premise of avoiding substantial changes to the existing mounting and placement of the in-line equipment already in place.

2.7.1 The first stage of laboratory experiments (LAB 1)

The goal of the first stage of laboratory experiments (LAB 1) was to test whether or not the conditions of station Graz-CST-CS1 could be replicated in a small-scale reactor in a laboratory environment (Figure 2-8). Due to the extent of uncertainties at this stage in the experimental process, the design of the reactors and the concept of the experiments were subjected to a limited budget. Once the findings of LAB1 showed promising results, the investigation of possible links between characteristic patterns in the time series and their causes during a second stage of laboratory experiments, focusing on these causalities was to be conducted. Otherwise, the approach of laboratory testing would have been abandoned in favour of field testing in operational environments with conditions similar to those in the CST.

Due to limited availability of two comparable spectrometer probes and scheduling conflicts, a set of factors, settings and effects of interest had to be defined. The durations of the trials of LAB 1 vary between three days and two weeks, since the experiments had to be coordinated with other research projects and the work load of the Institute’s laboratory. After the reactors were designed and their performance and limits tested, seven trials to test probe behaviour when exposed to varying successions of submersion media operated with different automatic probe cleaning configurations and subjected varying maintenance scenarios were conducted. An eighth trial, intended to mimic a possible worst-case scenario for probe fouling was conducted before evaluating the data and assessing the quality or significance of the generated results.

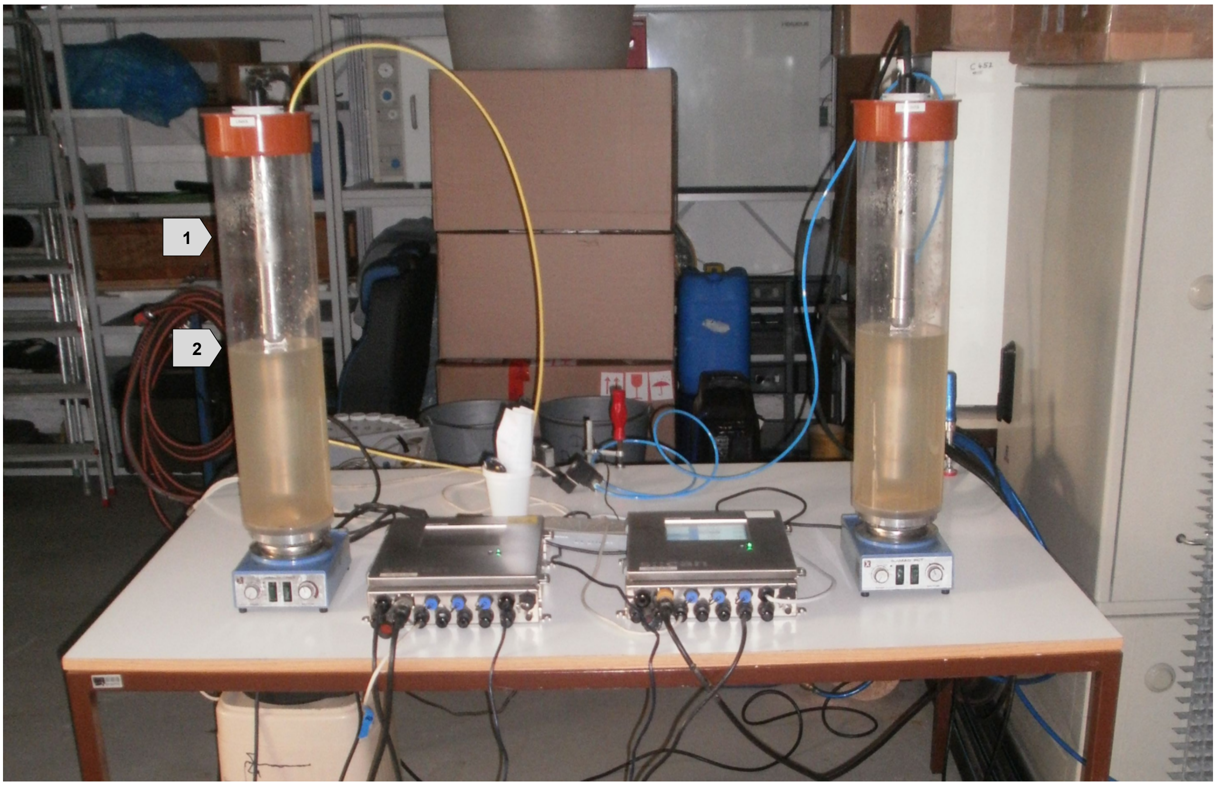


Figure 2-8: Experimental setup and equipment configuration for LAB 1

The monitoring equipment for LAB 1was available between March 2015 and July 2015 and for a short period at the end of September 2015. Given these time frames and after coordination with the Institutes' laboratory, the following time table (Table 2-2) was defined. Due to the described organisational constraints in the planning of the experiments, the list of trials was composed of experiments, which were conducted within Monday and Thursday of a single week, with the exception of two trials, spanning two work weeks of ten days.

Table 2-2: Time frames for trials of LAB 1

Trial ID	Starting Date	End Date	Approximate Duration in Days
1.1	March 10, 2015	March 12, 2015	2
1.2	March 16, 2015	March 19, 2015	3
1.3	March 23, 2015	March 26, 2015	3
1.4	March 30, 2015	April 9, 2015	10
1.5	April 13, 2015	April 16, 2015	3
1.6	May 26, 2015	May 28, 2015	2
1.7	June 1, 2015	June 3, 2015	2
1.8	August 24, 2015	September 3, 2015	10

Table 2-3 provides an overview of the contents and goals of the eight trials, highlighting the equipment configuration and target parameters and factors. For the exact duration, equipment configuration and settings of specific trials, see the respective tables in Appendix A, subsections A.3.1.1 and A.3.1.2, and the visualisation of the time series, provided in digital form in Appendix C.

To ensure maximum comparability, the two, simultaneously operated, reactors were filled, configured and operated identically with the exception of a single influencing factor. By keeping within this premise, symptoms resulting from a specific configuration could be distinctly linked to their source. To be able to ascertain changes in conditions in the reactors throughout a trial, grab samples were taken at the start and at the end of each trial, supplemented by additional samples in-between, depending on trial duration. Although the focus of these analyses was placed on sum parameters TSS and COD, extensive analytic programmes were conducted to amongst other constraints, evaluate the consequences of constant warming of the immersion medium by the spectrometer probes or changes in sample composition due to the continuous oxygen intake in the reactors by automatic probe cleaning flushes.

Table 2-3: Objectives and target parameters for trials of LAB 1

Trial ID	Trial Description and Objective(s)	Target Parameter(s) and Effect(s) of Interest
1.1	The objectives of Trial 1.1 were the testing of the laboratory setup and probe behaviour inside the small-scale, first-generation reactors. Automatic probe cleaning with compressed air was activated at the default settings from the CST with a 900 second interval and an assumed flush duration of 3 seconds. The cleaning pressure has to be limited to 2 bar in order to avoid damaging the reactors for all trials with GEN 1-reactors (Trial 1.2 to Trial 1.7).	Equipment testing Probe behaviour during a single immersion event
1.2	Trial 1.2 attempted to emulate the conditions in the CST when two immersion periods occur with a short, 24-hour-long, dry period in-between. The operational settings were identical in both reactors. Both probes were cleaned automatically with compressed air with a 900 second interval, with a flush duration of three seconds. The goals of this trial were the evaluation of advantages and disadvantages of the default automatic probe cleaning settings in the CST during immersion periods and to assess the effects of manual probe cleaning on probe accuracy and possible fouling, as well as to document the stability of the baseline of all parameters when a clean probe is operated in ambient air with a distilled water reference. One probe was cleaned manually at the beginning of the dry period.	Effects of manual probe cleaning with activated automatic probe cleaning Probe behaviour during a sequence of immersion events
1.3	Trial 1.3 was conducted with an identical configuration and sequence of events as Trial 1.2. In order to get a broader understanding of vertically installed spectrometer probes during submersion periods, automatic probe cleaning of both probes was deactivated throughout the entire trial. One probe was cleaned manually at the beginning of the dry period, allowing direct comparison between the results of Trial 1.2 and those of Trial 1.3.	Effects of manual probe cleaning without automatic probe cleaning Probe behaviour during a sequence of immersion events

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Trial ID	**Trial Description and Objective(s)**	**Target Parameter(s) and Effect(s) of Interest**
1.4	With the default automatic probe cleaning settings, compressed air with a 900 second interval and a flush duration of three seconds, this trial was aimed at assessing the effects introduced for Trial 1.2, when a longer dry period of seven days occurred between two immersion events. The focus was on possible fouling of one probe during the dry period in comparison to the stable baseline of the other probe, which was cleaned manually at the beginning of the dry period.	Effects of manual probe cleaning with activated automatic probe cleaning Probe behaviour during a sequence of immersion events
1.5	Trial 1.5 replicated the programme and objectives of Trial 1.2 with an acceleration of the automatic probe cleaning frequency to one compressed air flush every 300 seconds. As the flush duration stayed at three seconds, the increased number of cleaning cycles was expected to reduce sedimentation in the measurement window and to generate an overall more stable time series during immersion periods. If probe fouling occurred during the dry period, it is expected to be less distinctive due to the higher cleaning frequency.	Effects of a higher frequency of automatic probe cleaning flushes Probe behaviour during a sequence of immersion events
1.6	This sequence of three immersion periods of 20 hours, intermitted by short, four-hour-long dry periods with basic automatic probe cleaning settings (900 second interval, three second flush duration), during which one probe is cleaned manually at the beginning of every dry period, was targeted at verifying whether or not such short dry periods are enough for the formation of permanent plaque, drift or shift development.	Probe behaviour during a sequence of immersion events
1.7	While duration and basic event sequence of this trial were identical to Trial 1.3, no manual probe cleaning took place in this case. Automatic probe cleaning was deactivated during the immersion periods to ensure maximum residue and sediment accumulation in the measurement window. At the beginning of the dry period between the storage events, one probe was placed in an adapted version of a GEN 1-reactor, where it is cleaned automatically with tap water at a service pressure of 4 bar, with a three second flush duration at an interval of 900 seconds. The other probe was cleaned with compressed air at 2 bar (an increase in compressed air service pressure was not possible without compromising the seals of the reactors). All other settings were identical to Trial 1.3. Well aware of the frost risk, tap water served as prototype for possible alternative cleaning agents. Cleaning with tap water during the immersion periods was not possible due to the small size of the reactors, bearing risks for flooding of the laboratory and causing significant dilution of the CWS sample.	Comparison of automatic probe cleaning media Probe behaviour during a sequence of immersion events
1.8	Since no significant fouling (i.e. drift or shift patterns) was observed during Trials 1.1 through 1.7, the following worst-case scenario was implemented to possibly force this kind of negative behaviour in a vertically installed spectrometer probe, in order to avoid comparable situations on site. Spectrometer probes in both reactors were operated with compressed air at a default, 900 second interval, three second flush duration, setting, to ensure comparability. No manual probe cleaning took place. After a 24-hour submersion period, the water level was adjusted to reach the lower measurement window for 48 hours, followed by an extended dry period and another immersion event. This scenario was designed to simulate possible conditions at lower water levels of Graz-CST-CS1, when the sample might have higher pollutant concentrations and/or an overall composition, which resembles raw wastewater (not taking into account mineral sediments).	Testing of probe behaviour in a worst-case scenario Probe behaviour during a sequence of immersion events
		end of table

Since reactors of the first generation (*GEN 1*), as depicted in Figure 2-8, could hold at most seven litres of combined wastewater substitute, sampling for chemical analysis was limited by the constraint of keeping a sufficient water level above the measurement window of the spectrometer probes. Thus, the initial sample for chemical analysis had to be taken before the filling of the sample in the reactors. In case an extended profile of chemical determinations was required during a trial, a new CWS sample had to be used.

Nonetheless, sampling during trials caused considerable fluctuations in the distance between the level of the surface of the sample in the reactor and the optical measurement window of the immersed spectrometer probe. As this constraint is expected to have had a significant impact on sedimentation processes in the reactor, it had to be taken into account when interpreting and analysing characteristic patterns in the generated time series. At the start of a trial, or when a sample change occurred within a trial, CWS levels in the reactors varied around the mark depicted in Figure 2-8 [1] and were reduced to the minimum level, marked in Figure 2-8 [2] due to sampling for chemical analyses towards the end of the trial.

2.7.1.1 Setup for the first stage of laboratory experiments

2.7.1.1.1 Design and components of the first generation of reactors (GEN 1)

Stage one of the laboratory trials was intended to test the possibility of emulating the effects of the regularly changing conditions in CS 1 of the CST on spectrometer probes in a small-scale laboratory environment.

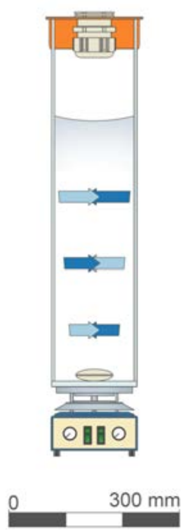

Figure 2-9: Agitation principle of GEN 1-reactors

The reactor design of the first generation (*GEN 1*) consists of acrylic glass cylinders, with an inner diameter of 140 mm and an inner height of 650 mm, providing a maximum sample volume of seven litres during probe operation. The cylinders were placed on magnetic stirrers by company *IKA*, providing a stable horizontal agitation stream (Figure 2-9). The sample in the reactors had to be covered at all times to meet the safety and hygiene regulations of the Institute's laboratory. As cover, a PVC blind flange for wastewater pipes with an outer diameter of 160 mm was used. Every reactor can house a single spectrometer probe, which is mounted via a *LAPP* cable screw clamp, positioned in a boring in the centre of the flange, thereby centring the probe in the reactor. Reactor covers have two additional borings. One was intended to pass the compressed air lining for the spectrometer probe's automatic cleaning mechanism, the other was designed to hold a sampling tube, if required. Both borings served as pressure releases during the experiments. All experimental reactors, composed of magnetic stirrer, acrylic glass cylinder and top lid serving as probe mount were designed to be operated individually. Four of these systems were built for LAB 1.

To ensure maximum flexibility of the trial schedule within the limits described in the previous section, the magnetic stirrers can be operated with automatic timer clocks.

For automatic probe cleaning, compressed air, at a theoretical maximum service pressure of 8 bar, or tap water, at a service pressure of 4 bar, was available. Compressed air, taken from the building's central distribution system, was cleaned from water and oil residue by a maintenance unit, but tap water had to be taken as is from the tap in the laboratory. While the maintenance unit allowed precise adjustment of the compressed air provided the spectrometer probes, tap water had to be used at the pressure level supplied at the tap. Compressed air pressure for automatic probe cleaning had to be limited to 2 bar at all times. On the one hand, this measure avoided damage to the reactors, on the other hand, it was a precaution to prevent the reactors from overflowing during cleaning flushes when filled. Tap water cleaning was used during the dry period of a single test run, with a slightly modified setup (Appendix A, section A.3.2.3.2). Due to these modifications, the applied water pressure was not an issue with respect to damage to the reactors.

Regardless of the applied cleaning medium, probe cleaning flushes were triggered automatically by magnetic valves. The compressed air lining was made up of six-millimetre polyamide tubes, connected by *Pneufit C* fittings from the company *Norgren*. Figure 2-10 shows the components and the design of GEN 1-reactors and their key measurements.

The measurement window of the spectrometer probes is positioned at *Level 0*, a compromise position, ensuring the functionality of the reactor agitation mechanism, while providing the deepest possible submersion of the measurement window in the CWS sample.

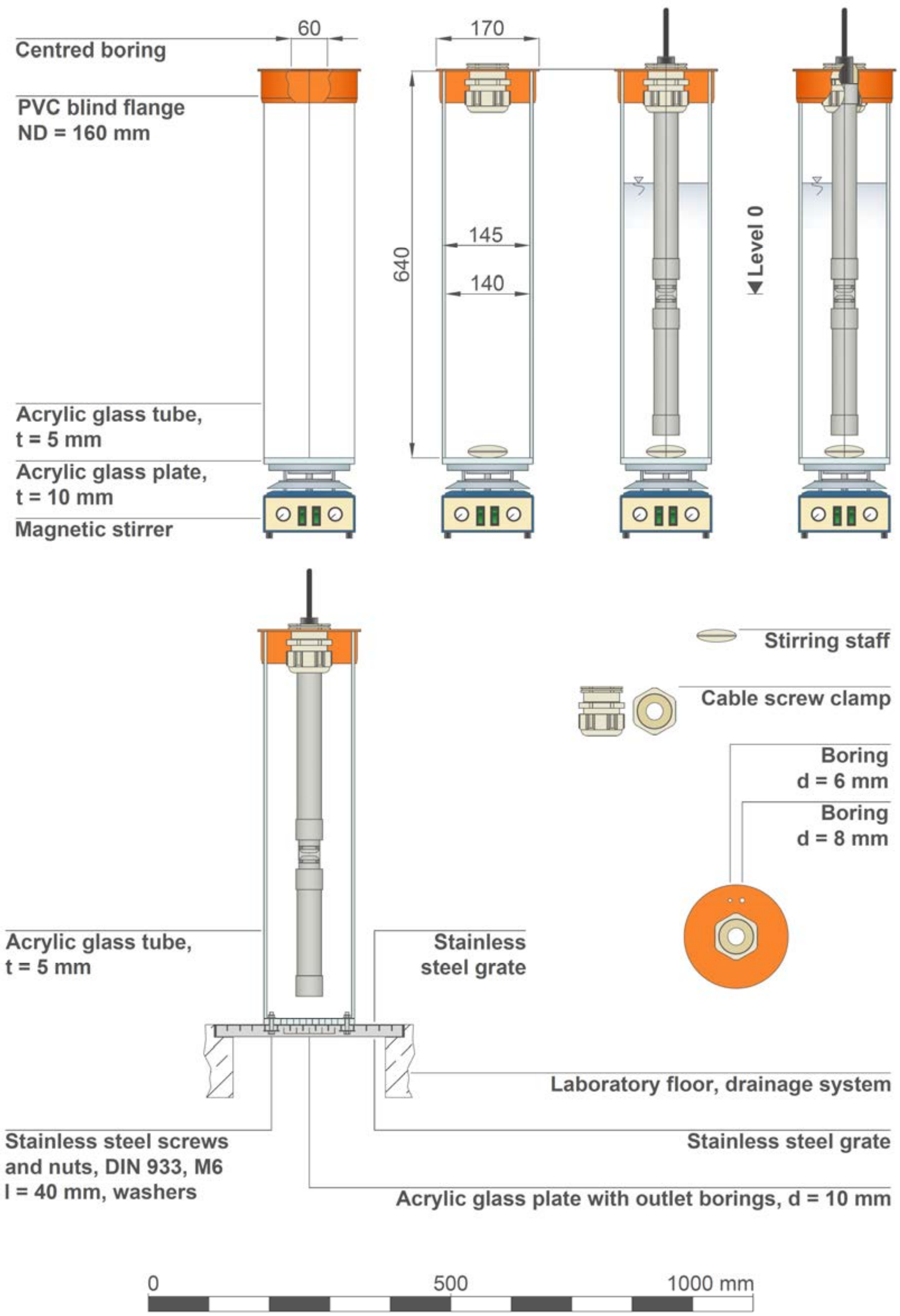

Figure 2-10: Components and key measurements for GEN 1-reactors

2.7.1.1.2 Trial setup and equipment configuration for LAB 1

For each trial of LAB 1, two fully functional reactors and two additional *containers* to keep the probes during dry periods were operated simultaneously. The additional containers are acrylic glass cylinders, identical to those used for the reactors, thus the probe mount fit their outer diameter and the probes could be placed in them by simply pulling them off a reactor and placing them atop a container. This setup was placed on a sturdy table to avoid interference between the systems (Figure 2-11).

Each reactor was assigned a single spectrometer probe, which was operated with an individual control unit and magnetic valve to trigger automatic cleaning flushes. All control units were synchronised by a notebook, which served as offline time server for the experiments (Figure 2-12) and guaranteed uniform time stamps.

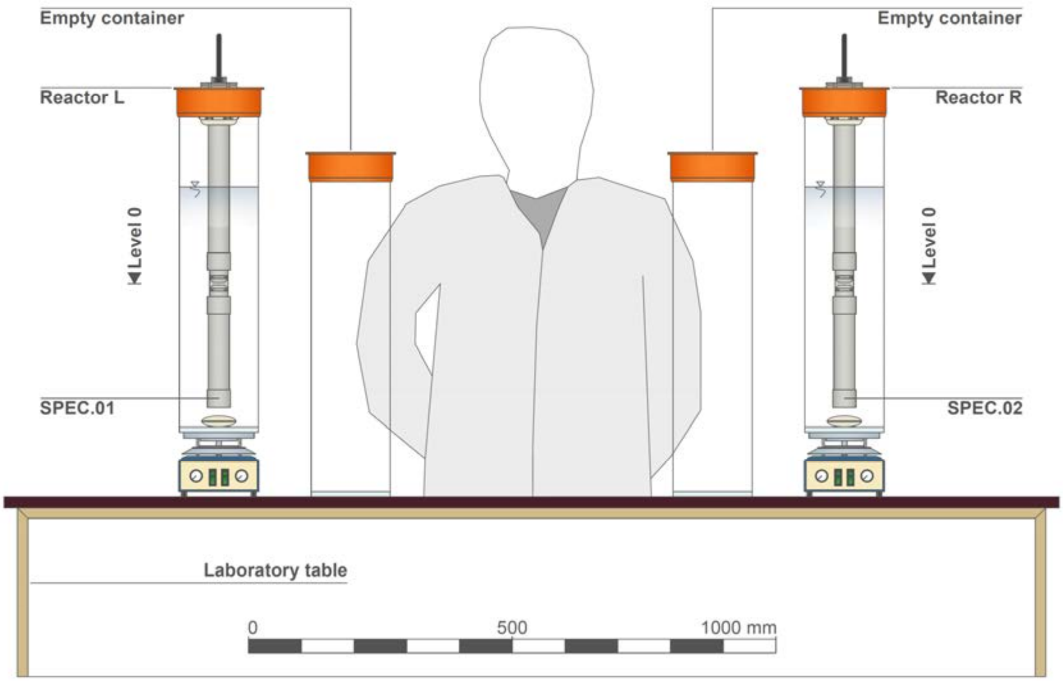

Figure 2-11: Basic setup for laboratory trials of LAB 1

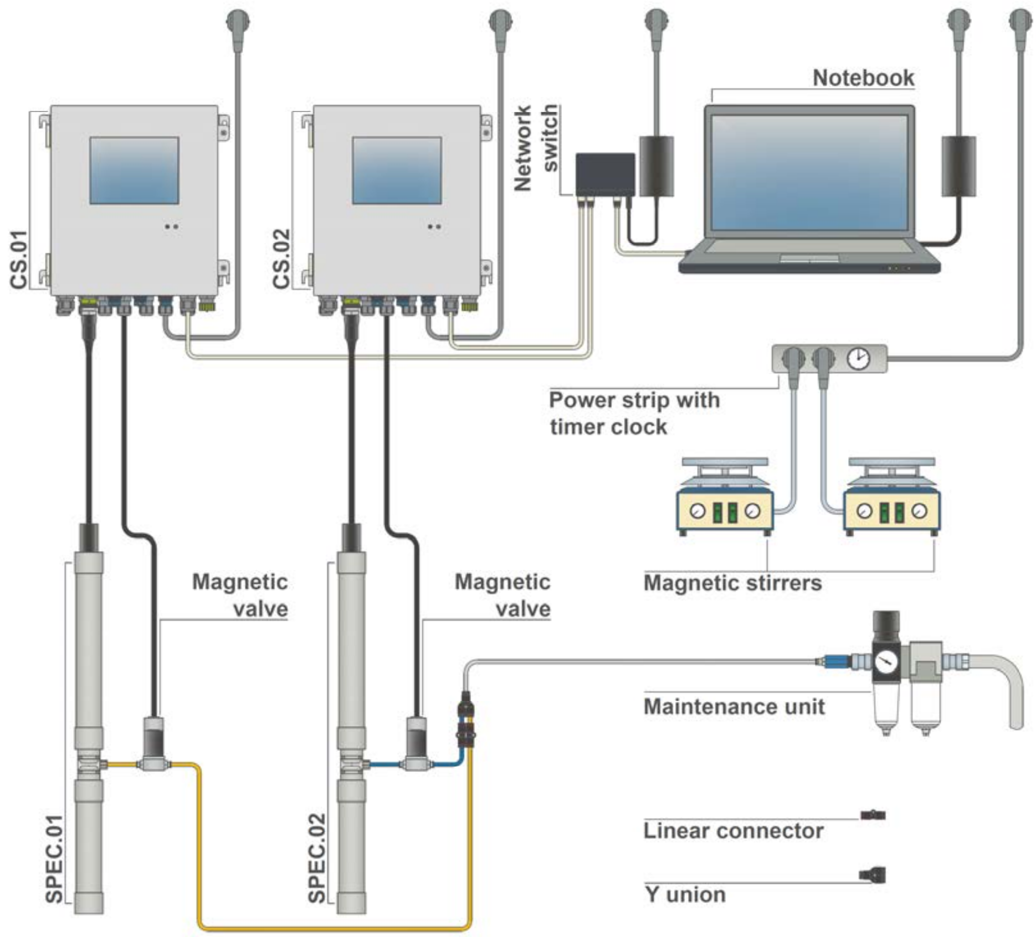

Figure 2-12: Basic equipment configuration for laboratory trials of LAB 1

2.7.2 Transition between stages of laboratory experiments

After completing the first stage of laboratory experiments in GEN 1-reactors, the resulting data was analysed and compared with the time series resulting from field testing programme FIELD 0. While a variety of characteristic patterns from station Graz-CST-CS1 could be explained, a series of behavioural characteristics was more pronounced in the laboratory results, than it was in the field data. While the preliminary findings led to the definitive conclusion that the existing situation on site, in the CST, could be replicated in a laboratory environment and the data resulting from LAB 1 merited further investigation, the limitations of the small-scale reactors became obvious. Hence, it was decided to devise a second generation of advanced laboratory reactors with the intent of eliminating most of the interference from the experimental setup on the behaviour of the spectrometer probes. These reactors should be able to house multiple primary probes at the same time and accommodate secondary equipment to widen the spectrum of information on the processes in this closed environment. The general idea was to optimise the design of the experimental setup and programme, based on the findings from FIELD 0, supplemented by the information derived from LAB 1, to emulate the conditions the probes at Graz-CST-CS1 are exposed to as accurately as possible. The following key aspects and capabilities required of the new setup were identified in order to achieve this goal:

- The introduction of a larger layout of the reactors was targeted at increasing sample volume and water head above the probes to reduce interference from the reactor cubature on probe behaviour (e.g. to generate more realistic sedimentation patterns), while leading to a more realistic pressure situation for automatic probe cleaning. Furthermore, the increase in scale was intended to reduce degradation effects of the CWS sample, as encountered during LAB 1. There it was a result of the warming of the spectrometer probes and their continuous compressed air intake in the closed system of the small-scale reactors.
- The possibility to use multiple probes in a single reactor at different levels and positions was required to compare different configurations in the same reactor. This was necessary to be able to simultaneously operate multiple reactors with different equipment configurations, given the limited time frame for additional experiments.
- Increased written and visual metadata documentation to be able to validate conclusions based on pronounced patterns in the time series was pursued. This also includes the use of secondary probes to document operating conditions in the reactors, especially during submersion and transition periods.
- The use of a new sample for every submersion event was intended to mimic variations in the composition of the combined wastewater occurring on site. Additionally, this approach was targeted at limiting degradation of the sample during a trial, in case longer submersion periods become of interest.

- An increase in the time scale, especially to be able to emulate longer dry phases between periods of probe submersion to facilitate the transition of residue in the measurement window of spectrometer probes onto permanent plaque was instituted.

2.7.3 The second stage of laboratory experiments (LAB 2)

Similar to the situation during LAB 1, a limited time slot during which the monitoring equipment was available, as well as the coordination with the Institute’s laboratory for the required chemical analyses were the key constraints in planning the trials of *LAB 2*. A fixed trial schedule was devised and implemented, before analysing the data after the fact, as was done for stage one. Since the time window for using the available equipment was even narrower than during LAB 1, the experiments had to be condensed to a point, where multiple factors had to be varied for different probes within every reactor for all trials. This deviation from the approach of LAB 1, where only a single factor had been modified in one of the two parallel-operated reactors, was made possible by the design of the second generation of laboratory reactors (*GEN 2*), in particular by the advanced, more flexible mounting system, offering the possibility of holding multiple probes. This mounting system, allowing the use of multiple primary and secondary probes in a single reactor, in combination with an increased effort in metadata collection rendered the sequential or parallel variation of multiple factors in every reactor manageable. To uphold basic comparability of the results from different reactors during each trial of LAB 2, they were filled with the same CWS sample and operated synchronously.

In the process of planning the condensed schedule, factors, parameters and settings which were investigated during LAB 1 were audited in order to isolate those to investigate further and to remove those which either did not merit or did not need further testing. As a consequence, tap water for automatic probe cleaning was not considered as a viable option for LAB 2. Probe cleaning with tap water in the closed system of the reactors was not possible during submersion periods due to the resulting dilution of the filled-in CWS sample. The cleaning effect during dry operation was analysed sufficiently in the course of Trial 1.7. Automatic probe cleaning periods exceeding a frequency of one flush per hour were removed from consideration as well as the advantage of a higher cleaning frequency had become obvious when reviewing the results of LAB 1.

While drafting the schedule for the second stage of laboratory experiments, entailed the removing of certain factors from consideration, the design of the new generation of reactors, based on the five key aspects defined in chapter 2.7.2, allowed the introduction of new factors and settings for testing in the course of LAB 2.

Figure 2-13: Reactors of GEN 2 with test configuration during the final stress test (left) and during an agitation period (right)

As the design of the GEN 2-reactors (Figure 2-13, left) led to an increase in sample volume to approximately 100 litres per reactor, a new agitation system in the form of a reactor aeration mechanism (Figure 2-13, right) was devised since no adequate stirring mechanism or reliable circulation pumps were available. The upheaval stream, which was intended to simulate the dynamics of the CST during charging and discharging periods, as well as to ensure homogeneous conditions when taking grab samples for chemical analyses, was created by a targeted stream of compressed air, pressed into the reactors via borings in its bottom plates (Figure 2-15). As a consequence, the axis in the centre of the agitation stream, which is oriented vertically in the first generation of reactors, has been tilted ninety degrees in the reactors of the second generation (Figure 2-14).

The increase in reactor size, height, diameter and therefore sample volume was implemented to approximate the pressure and sedimentation conditions of monitoring station Graz-CST-CS1 more realistically, with the objective to single out effects from LAB 1, which were suspected of being induced by the small scale of GEN 1-reactors.

In comparison to LAB 1, the time scale of individual trials was extended in order to gain insight in behavioural aspects of spectrometer probes over longer periods of time, primarily during longer dry periods between submersion events, and only second to that, during longer submersion periods. This aspect was thought to be particularly important regarding the identification of constraints and configurations responsible for probe fouling due to plaque formation during dry periods on site.

Accompanying chemical analyses to monitor changes in the sample during trials, as conducted during LAB 1, again focused on sum parameters TSS and COD, were undertaken throughout the experiments of LAB 2. Additionally, CODf, which was routinely analysed as a by-product of TSS determination was analysed for all grab samples. Other sum parameters, which were considered during LAB 1, were removed from the analytic programmes of LAB 2.

Since TSS and COD base lines, as measured by clean spectrometer probes were already analysed sufficiently during LAB 1, manual probe cleaning during LAB 2 took place at the end of dry periods to enable fouling on all probes. This also reflects the situation in the CST more realistically, as probe maintenance after storage events is only possible after a delay or buffer period for safety and scheduling reasons.

Based on the availability of the utilised equipment between the end of February and mid-June 2016, a trial schedule was devised for LAB 2. Table 2-4 shows the time frames for these trials as well as the duration for each one.

Table 2-4: Time frames for trials of LAB 2

Trial ID	Starting Date	End Date	Approximate Duration in Days
2.1	April 14, 2016	April 17, 2016	3
2.2	April 28, 2016	May 2, 2016	4
2.3	May 3, 2016	May 18, 2016	15
2.4	May 18, 2016	June 5, 2016	18

Four trials were conducted during LAB 2. Trials 2.1 and 2.2 were intended to test the performance of the newly designed reactors and to identify behavioural patterns of vertically installed spectrometer probes during submersion events. Effects of probe placement as well as data from secondary equipment were considered in linking causes and effects of such patterns. During Trials 2.3 and 2.4 the effects of a sequence of events with longer dry periods between them and manual cleaning towards the end of these dry periods were analysed with a focus on the detection of probe fouling during dry periods.

The trial objectives and parameters of interest can be found in detail in Table 2-5. The experimental programme of LAB 2, while attempting to emulate the conditions in the CST more accurately, was designed to substantiate findings from LAB 1 in order to relay those findings to future applications of spectrometer probes in operational environments with alternating condition similar to those encountered in station Graz-CST-CS1.

Table 2-5: Objectives and parameters of interest for the trials of LAB 2

<table>
<tr><th>Trial ID</th><th>Trial Description and Objective(s)</th><th>Target Parameter(s) and Effect(s) of Interest</th></tr>
<tr><td>2.1</td><td>While Trial 2.1 was meant to be the final testing programme for the equipment its main purpose is to test probe behaviour during an extended submersion period. After every 24-hour-interval, probe configurations (automatic probe cleaning settings and other factors) were altered. During the transition periods, the reactors were agitated via the installed aeration system in the reactors.
Since some probes were not available for this trial, Reactor 1 was only filled with CWS and aerated during the agitation periods to ensure comparability with the following trials, although no probes were installed in this reactor.</td><td rowspan="2">Probe behaviour while submerged in a larger reactor

Broader understanding of the operational behaviour of spectrometer probes and its possible influences

Sedimentation in the measurement window of spectrometer probes

Effects of different automatic probe cleaning configurations</td></tr>
<tr><td>2.2</td><td>Trial 2.2 was an extension of Trail 2.1 and attempted to widen the scope on spectrometer probe behaviour in the submerged state. After every 24-hour-period, probe configurations (automatic probe cleaning settings and other factors) are varied. During the transition periods, the reactors are agitated via the aeration system.
Turbidity probes are added at all three installation levels of Reactor 1 in order to provide the basis for a comparison between sedimentation in the reactor and particle accumulation in the measurement window of spectrometer probes.</td></tr>
<tr><td>2.3</td><td>Trial 2.3 was intended to test the behaviour of multiple spectrometer probes, positioned in two reactors with varying configurations. Variations in the configuration include probe placement, automatic probe cleaning settings as well as manual probe cleaning programmes. A sequence of submersion and dry periods was tested. Although a target duration of 24 hours was planned for storage events in the CST, longer submersion periods are tested, but separated by short agitation periods to emulate possible dynamics in the storage tunnel.
In order to accelerate the laboratory testing process, probe configurations were planned individually for the two reactors, but both were filled with the same CWS samples to ensure comparability of the resulting data.</td><td rowspan="2">Spectrometer behaviour during a sequence of submersion and dry fall events

Effects of different automatic probe cleaning configurations

Effects of longer dry periods between submersion events

Effects of manual probe cleaning</td></tr>
<tr><td>2.4</td><td>This trial was designed as an extension of Trial 2.3 by examining the effects of an increasing number of submersion periods, separated by extended dry periods. While submersion periods had an approximate duration of 24 hours, dry periods are prolonged. The idea was to mimic differences in the sequence of operating states, which might occur in the CST.
Similar to Trial 2.3 and in order to accelerate the laboratory testing process, probe configurations were planned individually for each reactor, but both reactors were filled with the same CWS samples to ensure comparability of the resulting data.</td></tr>
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2.7.3.1 Setup for the second stage of laboratory experiments

2.7.3.1.1 Design and components of the second generation of reactors (GEN 2)

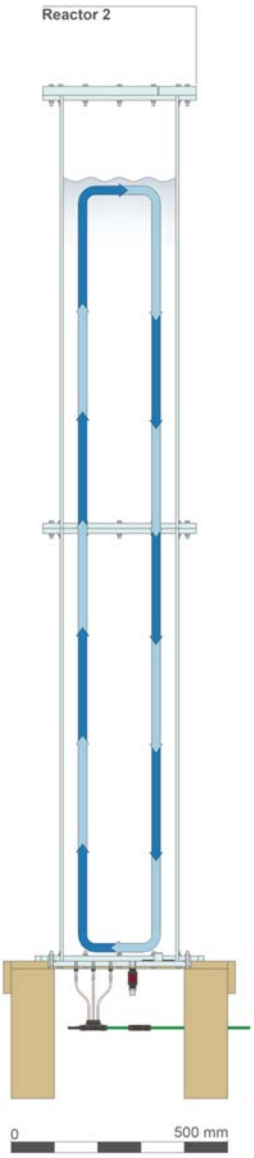

Figure 2-14: Agitation principle of GEN 2-reactors

In compliance with the previously stated goals for stage two of the laboratory trials, an experimental setup was designed, which at its core, maintained the basic ideas of LAB 1, while implementing changes based on the preliminary findings from the first set of trials. At the centre of the changes were the reengineering of the laboratory reactors and the use of a more extensive range of measurement equipment. The design of the reactors for LAB 2 was completely overhauled in comparison to LAB 1. The premise of the reengineering process was to emulate the operating conditions and constraints within the CST as realistic as possible within the confined space of the Institute's laboratory and to reduce interference from the experimental setup on the resulting data. Therefore, the scale of the two reactors was increased significantly. Each second-generation reactor can hold a maximum sample volume of 100 litres, at a maximum water level of 1800 mm at the beginning of a trial (Figure 2-13).

The hull of the reactors is composed of two acrylic glass pipes connected by a flange in the middle, which is owed to the height of the ceiling in the laboratory, a bottom plate, supporting the weight of the measurement equipment and the weight of the sample volume and a split lid at the top, which allows sampling and changing of probes during operation, while holding the remaining equipment in place. As during LAB 1, the reactors had to be covered at all times for safety and hygiene reasons. The slit separating the two components of the lid serve as pressure valve to the system (Figure 2-17) during reactor aeration and automatic probe cleaning flushes. The bottom plate contains borings for reactor aeration, which is used as a mean of agitation, instead of the magnetic stirrers applied during LAB 1. Placement of the nozzles on one-half of the bottom plate ensured a constant air bubble stream in the medium, as depicted in Figure 2-14. Only a small number of borings in the bottom plates held nozzles for compressed air intake, while the majority was sealed, but could easily be activated if needed (Figure 2-15). The bottom plate also holds a ball valve to adjust the water level and empty the reactors.

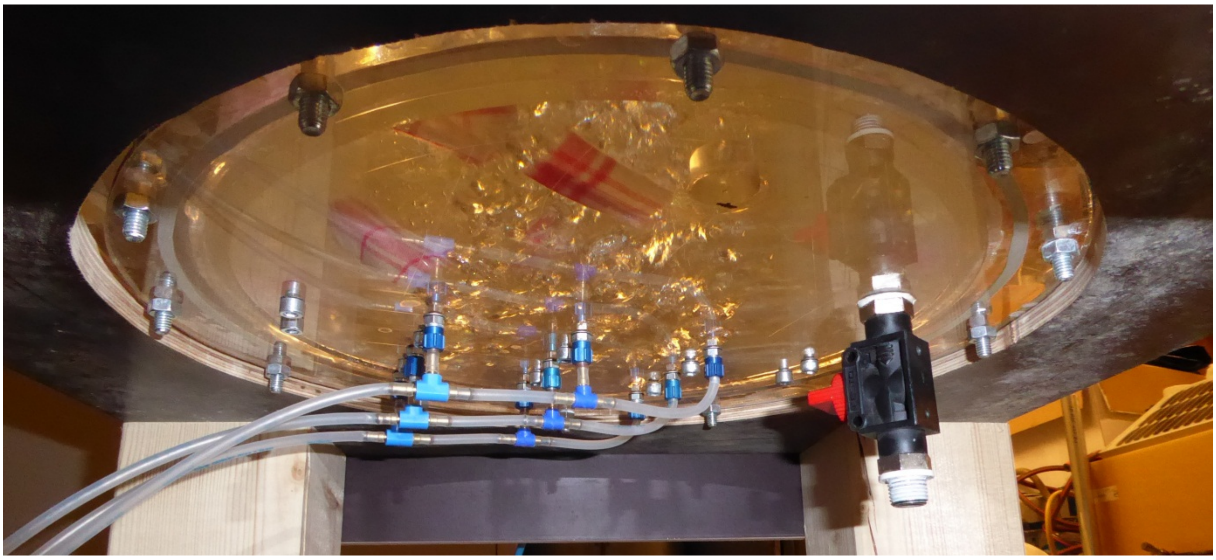

Figure 2-15: Details of the bottom plate with aeration system and outlet during tests of the agitation system

The measurement equipment was installed on a single mount, made up of a sealed, stainless steel inner duct or guide tube and an outer cladding tube made of plastic pipes, which hold the used probes via a combination of pipe clamps, lock nuts and threading rod elements (Figure 2-16). The cladding tubes are interconnected via small socket head screws, some of which are used to adjust and fasten the horizontal position of the cladding elements on the inner duct. The combination of the single element inner guide and the (dis-)mountable set of outer tubes is a prerequisite for flexible operation of the large reactors under the low laboratory ceiling.

Figure 2-16: Outer cladding tube elements, probes mounted with pipe clamp systems

Each reactor was placed on a sealed wooden substructure, with a pivotal aperture, in which the reactor aeration system, as well as the bottom outlet, was placed. Furthermore, this design allows the documentation of sedimentation effects by visual inspection and recording of the same via camera.

Since the top of the reactors had to be closed during operation for safety reasons, the mounting system was included in the top lid (Figure 2-17). The two elements of the top cover contain two borings, one keeping the mounting system for the probes in position, the other one to hold the power and compressed air lining for the probes. The gap between the two elements of the cover ensures circulation while avoiding splash water and other safety risks.

While the mounting system was held in place by a boring in the cover at the top, an acrylic glass mandrel, which was fitted to the inner diameter of a connector element at the end of stainless steel inner guide tube, serves that purpose at the bottom. It was surrounded by a layer of acid-proof rubber (Figure 2-18), to minimise dynamic stress on the bottom plate when probe configurations are changed. The mounting system allows placing the probes at the centre of the reactor to avoid interference from the hull.

Figure 2-17: Split top lid (left) and mounting system after reactor discharge (right)

Identically to the setup of LAB 1, compressed air at a theoretical maximum service pressure of 8 bar was available for automatic probe cleaning and reactor aeration. To avoid overflowing of the reactors or splash water the maximum pressure for trials was restricted to 2.5 bar. The compressed air lining was made up of six-millimetre polyurethane tubes, connected by *Pneufit C* fittings manufactured by the company *Norgren*. The compressed air taken from the building's utility system was cleaned of water and oil residue by a maintenance unit. While automatic probe cleaning was activated automatically by magnetic valves, a manual restrictor in combination with a manually operated ball valve was used to operate the reactor´s aeration system (although automatically timed reactor aeration would have been possible).

Like the reactors of LAB 1, those of LAB 2 were also designed in a way that allows individual operation. During LAB 2 a variety of probes and measurement system was used. The combination of in-situ online probes and hand-held laboratory devices was possible due to the increased dimensions of GEN 2-reactors and provided deeper insight in the processes within the reactors, in the hopes of being able to distinguish clearly between effects caused by the experimental setup and those resulting from the spectrometer probes.

The following figures, Figure 2-18, Figure 2-19 and Figure 2-20, depict the installation and its components to scale and in detail. All depicted metal parts of the reactors are made of stainless steel.

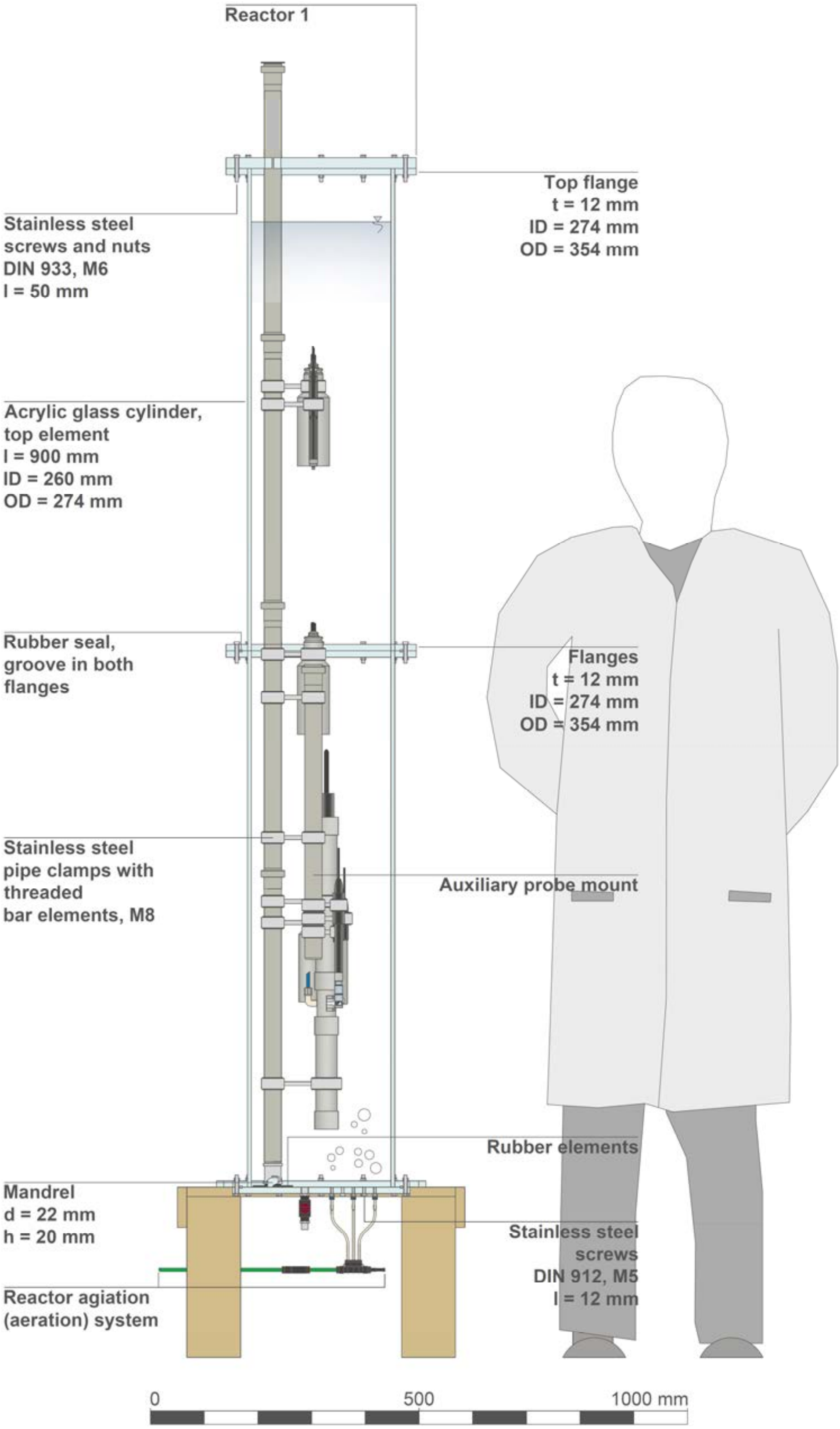

Figure 2-18: Components of GEN 2-reactors (1/2)

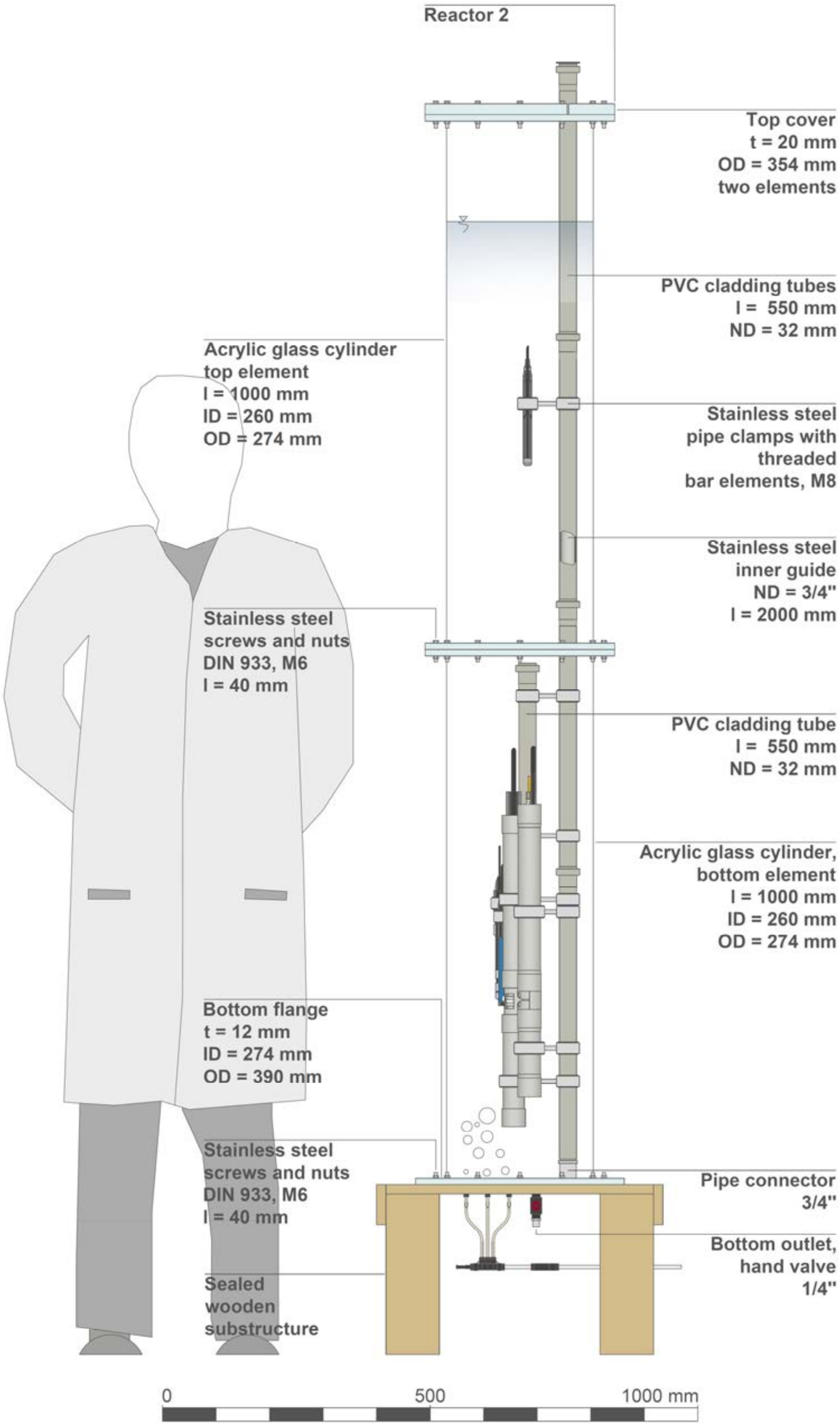

Figure 2-19: Components of GEN 2-reactors (2/2)

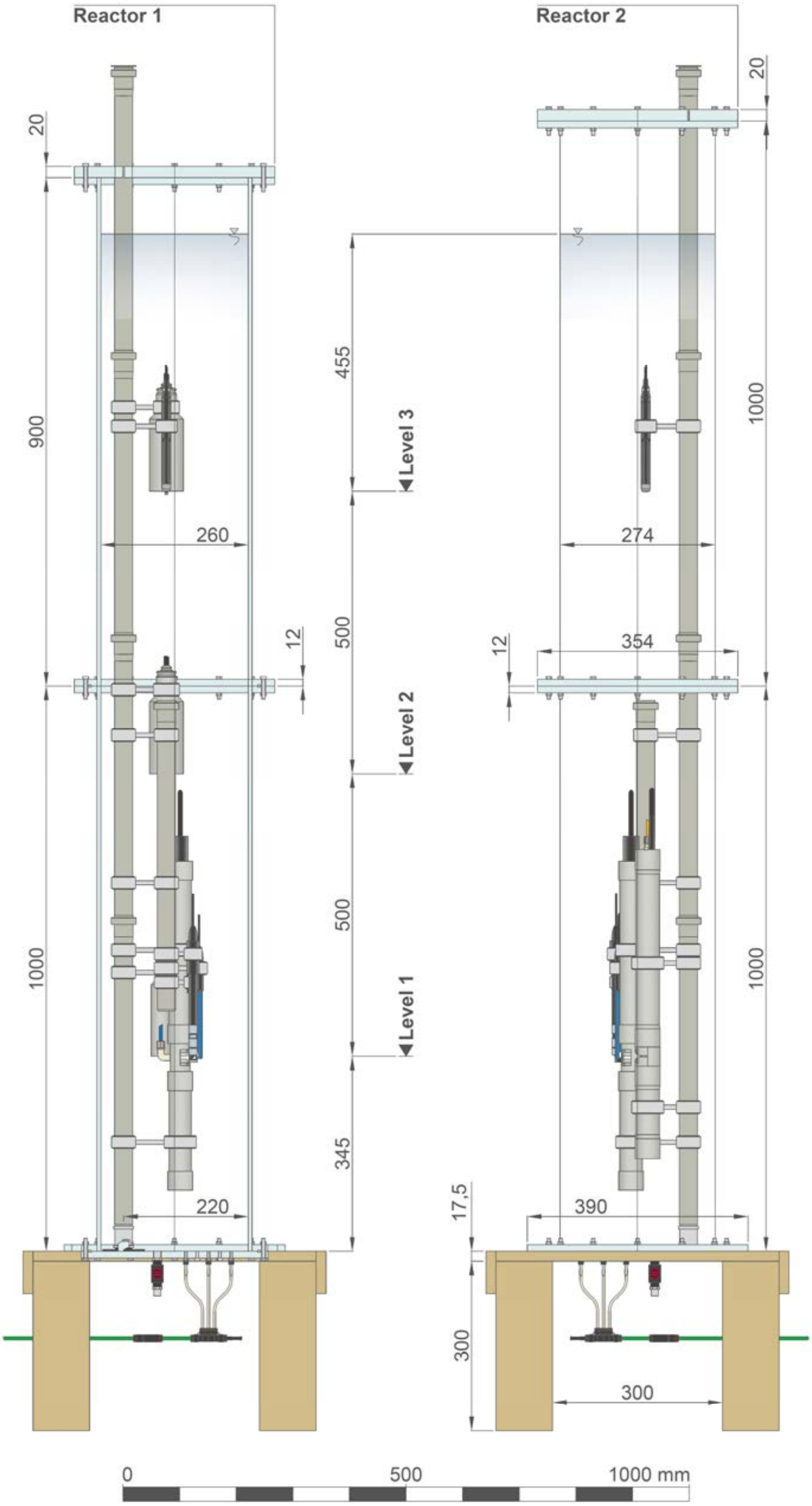

Figure 2-20: Key measurements and installation levels of GEN 2-reactors

2.7.3.1.2 Trial setup and equipment configuration for LAB 2

Much like the experimental layout of LAB 1, the basic setup for LAB 2 consisted of two synchronously operated systems. But due to scheduling conflicts with other projects and limited time windows of equipment-availability, a deviation from parallel sensor placement was imperative to generate the maximum possible amount of information. Multiple probes of different manufacturers were operated in each reactor, combining hand-held laboratory probes and in-situ online probes. The equipment configuration of the two operated reactors was different within all four trials of LAB 2.

All measuring systems were timely synchronised at the beginning of a trial. When possible, synchronisation was achieved via a laptop. Due to a limited number of interfaces, control units of secondary probes could only be synchronised manually by triggering the initial measurement at the beginning of a trial. Control units of in-situ online probes were synchronised via laptop, serving as offline time server in the laboratory. Time series generated by the primary and secondary equipment utilised during a trial was synchronised in post-processing. The applied programme scripts can be found in Appendix B. Data of primary probes was stored on the respective control units and transferred to a back-up hard drive after the end of a trial. Secondary probes by company *WTW* logged the data on the internal memories of their control units of type *Multi 3430*, which was transferred onto back-up hard drives afterwards. Secondary probes by company *Hach Lange* were operated with an *HQ40d* control unit and with a notebook serving as data logger.

Inside the reactors probes were positioned at three levels (Figure 2-20 and Figure 2-21), with Level 1 at the bottom. The distance between Level 1 and the bottom of the reactor was defined as 345 mm, matching the specifications of the installation in the CST. The distance between Level 1 and Levels 2 or 3 amounted to 500 mm and 1000 mm respectively, leaving a distance of at least 300 mm between the surface of the combined wastewater sample in the reactor and the sensors of the probes at the top level at any time. The distances were measured from the bottom of the reactor to the centre of the measurement window of spectrometer probes and to the level of the sensors of other probes. While the probes could only be partially immersed during LAB 1, they were submerged entirely in the GEN 2-reactors, emulating the operating conditions of station Graz-CST-CS1 more realistically.

Figure 2-22 shows the equipment configuration for Trial 2.4. It represents the maximum number of probes in both reactors during any trial of LAB 2. In addition to the alternating placement of the probes within the reactors, they were switched between them throughout the four conducted trials. Based on availability of the equipment, some of the probes were only used for a selected number of trials.

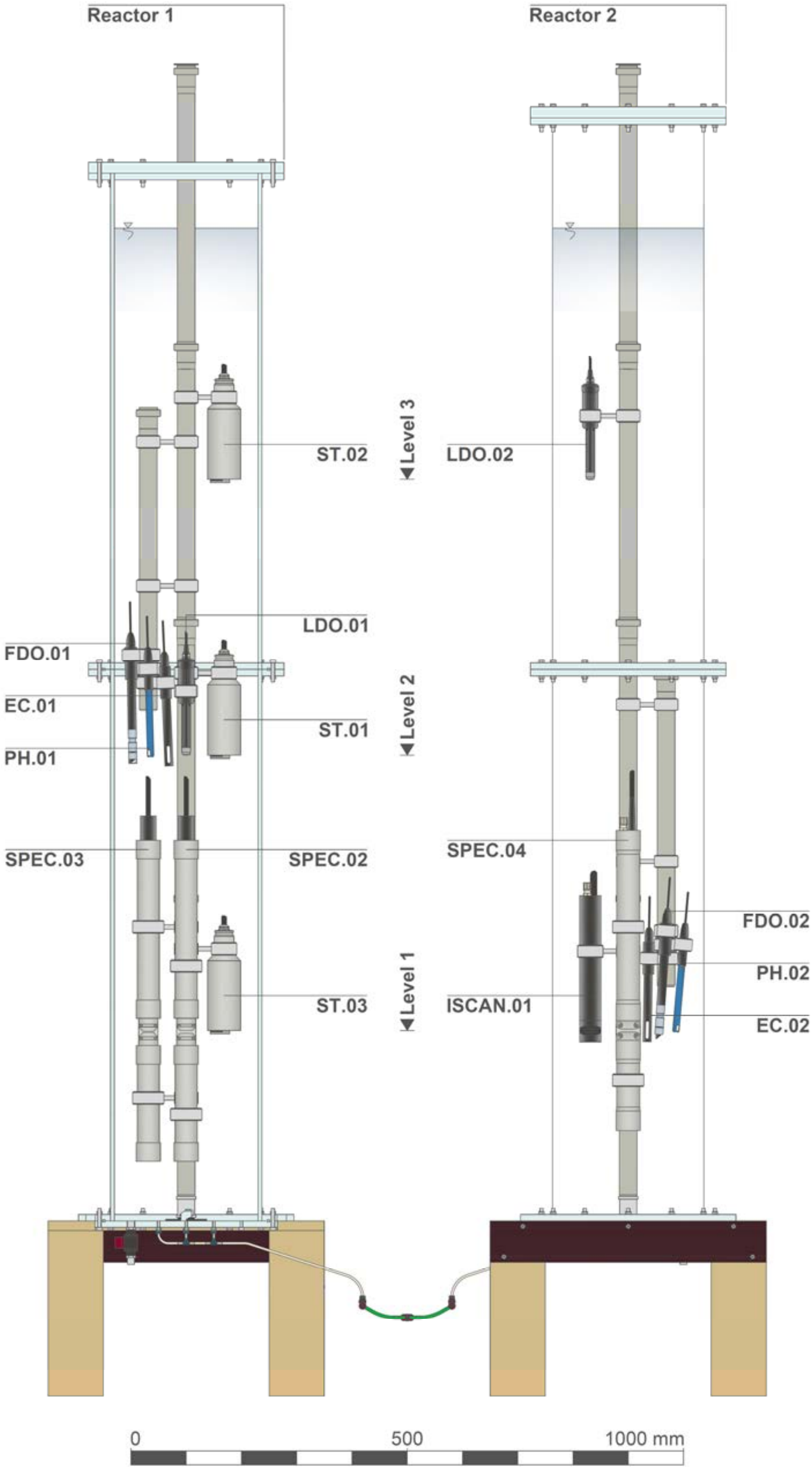

Figure 2-21: Exemplary setup and probe placement options during Trial 2.4 of LAB 2

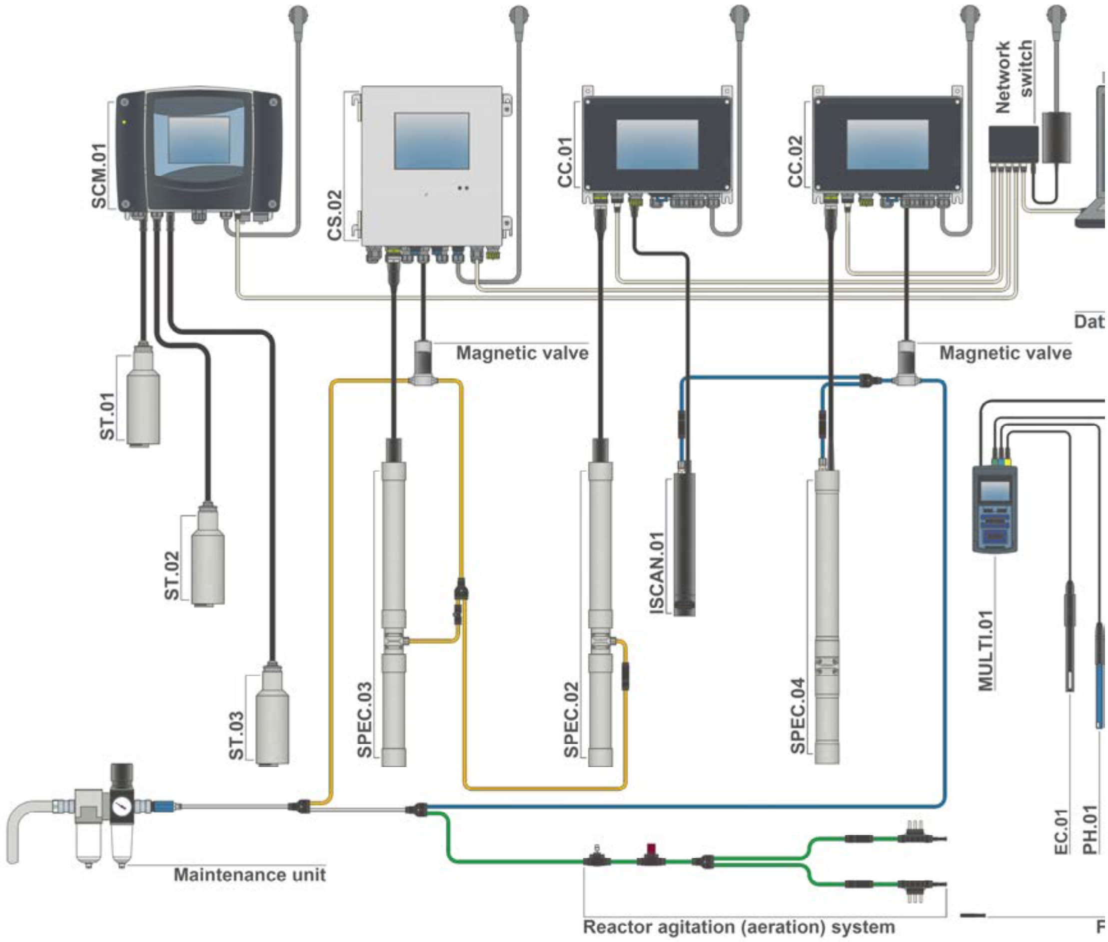

Figure 2-22: Most extensive equipment configuration during Trial 2.4 of LAB 2

2.8 Field testing programme at WWTP Graz (FIELD 1)

Since the beginning of regular operation of water quality monitoring installation Graz-CST-CS1 was not yet scheduled by the time this thesis was submitted, a field testing programme was designed to test a spectrometer probe under alternating conditions similar to the CST at an existing monitoring station at the end of the overflow channel of the combined wastewater storage tanks at WWTP Graz. This monitoring station is denoted by the term *Graz-WWTP-CSO*. The field testing programme conducted at this site is referred to as *FIELD 1*. The position of the monitoring station in the context of the storage tunnel CST and wastewater treatment plant is highlighted in Figure 1-1 in chapter 1.2.

Figure 2-23: Monitoring installation Graz-WWTP-CSO during FIELD 1

This monitoring site presented itself as optimally suited for additional testing, since the combined wastewater discharged through the overflow channel is comparable to the medium which is stored in the CST during storm events.

While certain characteristic patterns in the behaviour of spectrometer probes could be identified by reviewing the data resulting from the initial field testing programme FIELD 0 in combination with the results from the laboratory experiments of LAB 1 and LAB 2, a number of additional parameters could be included in the scope with FIELD 1. Trials of FIELD 1 were conducted between early May and the end of September 2016, amounting to a total of five months of continuous data recording. During the entire period, the in-line equipment was operated with a measuring interval of 120 seconds, while only minor changes to its configuration were recorded.

The overflow channel housing the in-line monitoring equipment of station Graz-WWTP-CSO is characterised by a circular cross section with a diameter of 2000 mm and with only minimal longitudinal slope (Figure 2-23). Water level and flow rate sensors were used to determine the intensity and duration of overflow events. The distance of 200 mm between the centre of the measurement window of the installed spectrometer probe and the bottom of the cross-section was used to distinguish between overflow events and dry periods, defining the submersion state of the probe as key factor for the analysis of its behaviour.

Figure 2-24: Side view of the floating pontoon in Graz-WWTP-CSO where the spectrometer was installed after an overflow event (Image: Hofer, 2016)

The flexible installation of the spectrometer probe at the bottom of a floating pontoon (Figure 2-24) which was fixed movable by steel cables from the ceiling, offered means to evaluate the possible use of a similar installation in the CST. It allowed extending the range of factors for performance testing of spectrometer probes beyond the constraints imposed by the current monitoring station in the CST and thereby the laboratory setups of both generations. Hence, a number of additional settings and factors, e.g. horizontal probe installation, which could not be tested in the laboratory, but might be relevant for future operation of Graz-CST-CS1, could be taken into consideration during FIELD 1.

Figure 2-25: Clogging of the cladding tube in which the spectrometer probe is installed after an overflow event (Images: Hofer, 2016)

While the entanglement of hygiene products around the cladding tube at the bottom of the floating pontoon (Figure 2-25), in which the spectrometer probe is installed, was a factor for maintenance of the installation in general, the design of the pontoon prevented clogging of the measurement window of the probe.

Comparison of the time series from the flexible-installed system used during FIELD 1 with the results from the preceding experiments provided an opportunity to identify characteristic patterns that are induced if applying an inflexible installation enabling a more definite distinction between effects that can be linked to the interaction between the probe and the medium and to those caused solely by the design of the installation. Thus, data resulting from FIELD 1 enabled a validation of the findings of the initial field testing programme and the subsequent laboratory experiments. In doing so, this last trial programme made a significant contribution to the optimisation of operation and management of monitoring station Graz-CST-CS1 and all comparable systems.

2.8.1 Equipment, placement and configuration of station Graz-WWTP-CSO (FIELD 1)

The in-line component of monitoring station Graz-WWTP-CSO is centred in a circular, concrete sewer profile with an inner diameter of 2000 mm. The floating pontoon in which the spectrometer probe was installed has a length of 1500 mm and a width of 400 mm. It is mounted via stainless steel ropes from the top of the sewer to ensure a minimum distance of 200 mm between the centre of the measurement window of the probe and the bottom of the cross-section, while allowing the pontoon and therefore the installed probe to move laterally and vertically within a limited range. The spectrometer probe itself was fixed in a plastic cladding tube, horizontally mounted at the centre of the bottom of the pontoon (Figure 2-26).

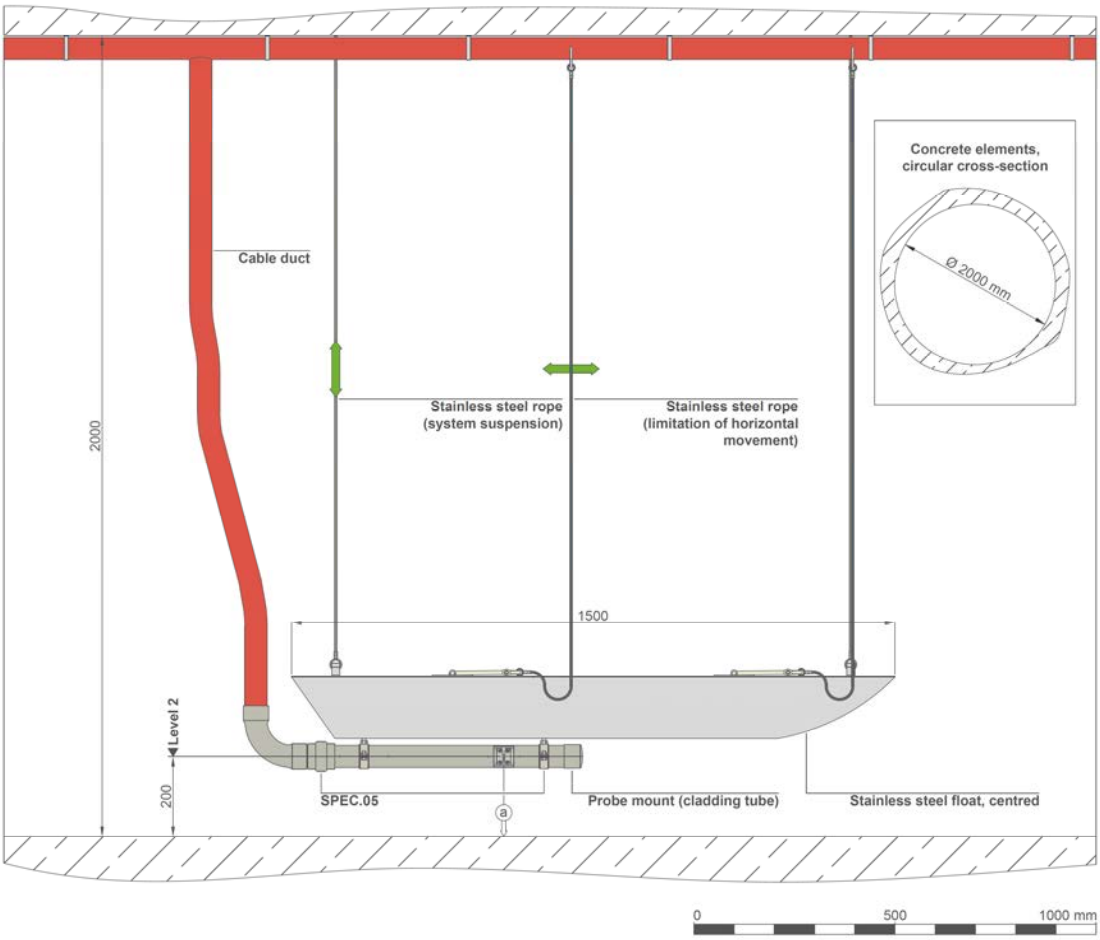

Figure 2-26: System sketch of monitoring installation Graz-WWTP-CSO during FIELD 1

Water level and flow rate sensors were installed upstream of the pontoon as required by the respective manuals. A more detailed representation of this monitoring station, which includes these secondary probes, can be found in Appendix A, subsection A.3.3.4.1.

Power supply, data cable and compressed air lines are bundled in flexible tubes mounted at the end of the pontoon and the top of the sewer cross-section, leading to a water proof control cabinet above the sewer pipe. It contained the control units and data loggers for all probes, as well as a link to the SCADA system of the wastewater treatment plant and an internet connection for remote access. The maintenance unit for compressed air regulation and cleaning and a pressure sensor for the supplied compressed air are also placed in this cabinet. Compressed air for automatic probe cleaning was taken from the internal distribution system of WWTP Graz. Figure 2-27 shows the configuration of probes, sensors and control units used in the operation of this monitoring station.

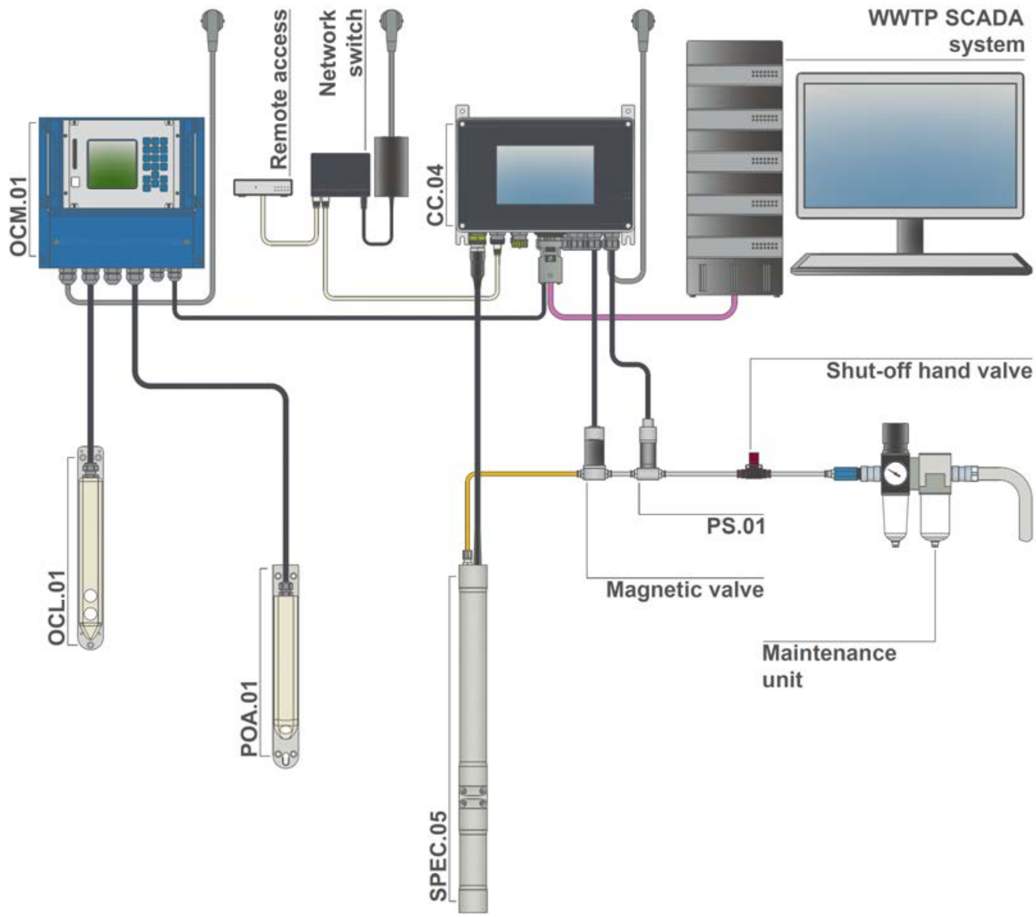

Figure 2-27: Equipment configuration of station Graz-WWTP-CSO during FIELD 1

2.9 Data visualisation, analysis and interpretation

The results from laboratory experiments and field testing programmes were processed using the open-source programming language *R* from the *R Foundation for Statistical Computing* in version 3.3.1 and multiple additional packages. The packages used for each script are listed at its beginning. The code used for data processing and visualisation can be found in appendices B and C.

In both, in the field and in the laboratory, extensive metadata documentation in the form of written notes, pictures and video clips was undertaken. This detailed documentation can be found in *Microsoft Excel*-files and in a compacted version, incorporated in the text files containing processed and validated reactor and probe data in the respective directories of Appendix B. The idea behind the approach for data collection and processing was to provide a well described operational status for operational environments and the equipment installed in them at any given time throughout a trial. Key parameters were selected to describe the operational status of the system, the placement and the configuration of the probes and a variety of management aspects (e.g. probe maintenance).

The concept is aimed at reducing the required efforts in identifying the sources of characteristic probe behaviour of spectrometer probes and at providing a foundation for a possible implementation of a pre-validation process for the time series as described in Bertrand-Krajewski et al. (2003), though based on an extended set of parameters. Another system to identify and flag or remove invalid data based on metadata and specific behavioural characteristics was implemented in Schilperoort (2011).

2.9.1 Data processing and metadata assignment

Metadata describing the status of the components of an experiment at any given point in time was collected during all trials. While some of it (e.g. the configuration of a probe and its placement in an installation) can be clearly linked to probes and their control units, other information is associated with the laboratory reactor or the installation site (e.g. the duration of a discharge event or the manipulation of a monitoring station).

To assign the collected metadata to the generated time series of the monitoring equipment an identifier for the stage of laboratory experiment or field testing programme was introduced (*LAB* or *FIELD*) and all of the trials within a stage were assigned a trial identification number or *Trial ID* (e.g. *Trial 2.1* or *Trial FT.1*). These identifiers in combination with the timestamps associated with each measurement and piece of metadata were utilised to manage and combine the output from the experiments.

The main data categories are illustrated in Figure 2-28. In this representation fields with rounded corners represent information which is only relevant for field trials. Information in fields with skewed corners at the top is pertinent to laboratory experiments exclusively. The abbreviations and colours in this figure are used throughout the graphical and tabular representations of the data and findings in the following chapters. A detailed description of the used colour scheme is provided in section A.2 of the appendix.

Most of the categories in the hierarchy of Figure 2-28 contain multiple sub-categories and settings. A more detailed account is provided in chapters 2.9.1.1 through chapter 2.9.1.3. The visualisation concept for the data which integrates the collected information in time series plots is presented in chapter 2.9.2. These plots are the basis for the analysis of the findings, as described in chapter 2.9.3 and discussed in detail in chapter 3.

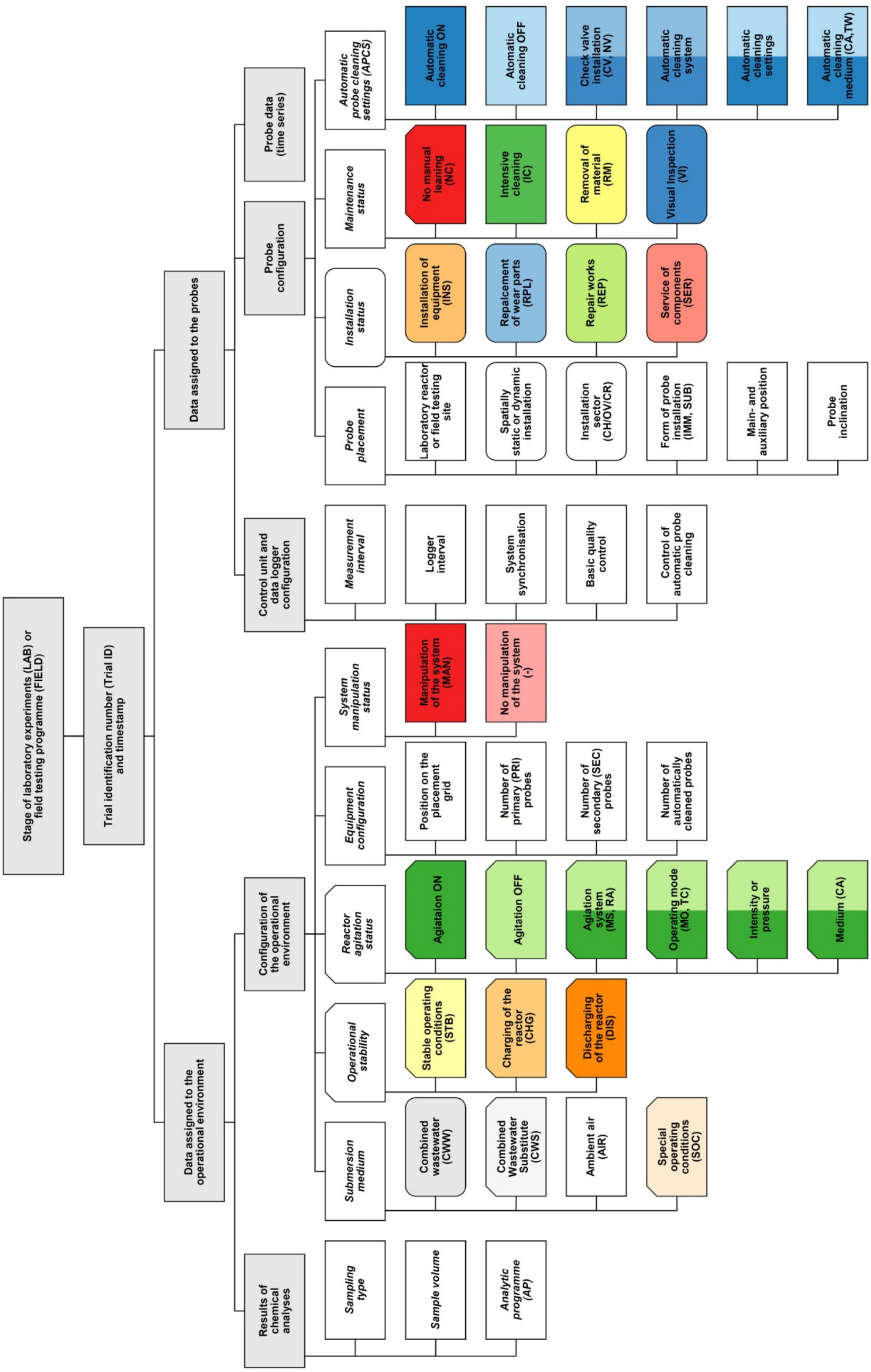

Figure 2-28: Data management for laboratory experiments and field trials

2.9.1.1 Metadata assigned to the operational environment

At the centre of the data associated with the operational environment is the submersion medium of the probes. In the case of the laboratory experiments, the probes are either operated in CWS or in the ambient air (*AIR*) in the reactors. On field installations sites, the probes can be immersed in CWW or exposed to the ambient air in the structure. The term *ambient air* was selected to reflect the significant differences in temperature, humidity or the occurrence of a continuous draft in laboratory reactors or sewers in comparison to the climate outside these closed environments housing in-line probes.

Another key factor is the manipulation of the system's probes or mounts (e.g. during inspection or maintenance of the equipment). In case of the laboratory experiments, the stability of the medium in the reactors is considered as an important factor, which is attributed to the operational environment.

For all laboratory and field installations a placement grid was established to be able to assign behavioural patterns to possible side effects rooted in the position in the operational environment. This placement grid is structured hierarchically by assigning each probe an installation level, a main and an auxiliary position. Examples of such grids can be found in Figure 2-5 or Figure 2-20. In detail, the applied basic placement concept consists of three vertical installation levels, combined with sets of three main and three auxiliary positions, which define the position of a probe in the cross-section at a certain level. In case of the monitoring stations Graz-CST-CS1 and Graz-WWTP-CSO, an additional distinction was made between equipment installed in-line, meaning inside the storage chamber or the overflow channel and equipment placed in control rooms or control cabinets above ground. If relevant, the inclination of the installed probes was included. Details regarding the placement concept for individual installations are provided in Appendix A, section A.3.3, in tabular and graphic form.

The results of chemical analyses of submersion media are assigned to the operational environment.

For the experiments of LAB 2, the timestamps and specifications for automatic probe cleaning flushes were assigned to the reactors and to the probes. This need for redundant data assignment arose with the possibility of installing multiple probes in one reactor. Thus, probes with a deactivated automatic cleaning feature could be installed in a reactor alongside probes with activated automatic probe cleaning. As a consequence, the influence of automatic probe cleaning flushes in the system on probes without active automatic cleaning feature became of interest. By assigning the corresponding information to the reactors and to the probes, it was ensured, that no information was lost. The number of installed probes and their automatic cleaning status was also of relevance, when assessing degradation of CWS samples in laboratory reactors.

Data assigned to the state of an operational environment is included in the background colour and the operating status bars of the plots used for data analysis.

2.9.1.2 Metadata assigned to the probes

Probes were assigned metadata, depending on their category, placement, inclination, management efforts and configuration. While the category distinction only includes whether a probe is assigned to the primary or secondary class of probes, the placement information for a site or reactor-specific grid, as described in the previous section, comprises the following information, always in the given order:

- In case of field installations, the distinction between installation in line (overflow channel *OV* or storage chamber *CH*) or in the control room or cabinet (*CR*),
- in case of the laboratory trials, the reactor in which the probe is installed,
- the vertical installation level (e.g. *Level 1*),
- the main position in the cross-section at a certain level in the form of an upper-case letter,
- if relevant, the auxiliary position (on an additional mount etc.) in the cross-section at a certain level in the form of a lower-case-letter and
- the inclination of the probe in degrees, if relevant. (The inclination is counted positive clockwise, negative counter-clockwise. Vertical installation with downward-facing sensors is considered as a probe inclination of 0 degrees).

For every installation, a detailed drawing, marking the levels and positions can be found in Appendix A, under item A.3.1.2 for LAB 1 and LAB 2, and under items A.3.3.2 and A.3.3.4 for FIELD 0 and FIELD 1 respectively.

The second key aspect of probe-related metadata is its automatic cleaning configuration. These automatic probe cleaning settings *(APCS*) are always comprised of a specific sequence of settings, as presented below. If a certain parameter is not available for a probe it is marked with a hyphen. Variations of a parameter throughout a trial are represented by a lower-case delta (*δ*). Unknown parameters are represented by a question mark (*?*). APCS are represented by the following sequence of parameters in all tables and plots:

- The installation status of a check valve (*CV*) or lack thereof (*NV*) in the compressed air lining,
- the automatic cleaning status (*ON*, if activated or *OFF*, if deactivated),
- the cleaning medium (compressed air, *CA*, or tap water, *TW*),
- the cleaning interval in seconds,
- the duration of a cleaning flush in seconds,
- the gap between the end of the cleaning flush and the subsequent measurement in seconds,

- the status of the wiper blade (*ON*, if activated, otherwise *OFF*) and
- the interval of wiper blade movements in seconds.

According to the cleaning recommendations defined in their manuals, in the course of the laboratory trials of LAB 1 and LAB 2, probes were either:

- Not cleaned (*NC*) manually or
- intensively cleaned (IC).

This probe management task was adapted and extended for field testing programmes FIELD 0 and FIELD 1, during which probes were subjected to:

- Intensive cleaning (*IC*),
- the removal of material (*RM*), e.g. hygiene products or
- visual inspection (*VI*).

Since the documentation of the installation status of pieces of equipment was of particular interest during the longer field testing programmes, four states of probe installation were established. Periods, during which the equipment was manipulated, but no form of manual cleaning took place, were assigned one of the following categories:

- Probe installation (*INS*), which describes the addition or removal of a probe from the monitoring station,
- repair works (*REP*), a term that sums up all forms of repair work on the mounting system,
- replacement (*RPL*) of wear parts of probes and sensors and
- component service (*SER*), which combines minor tasks during day-to-day operation, like discharging of the oil-separators of maintenance units for compressed air cleaning.

Appendix A contains tables with a sequence of configurations for every probe used during laboratory and field trials. The information on LAB 1 and LAB 2 is provided in section A.3.1.2, for FIELD 0 in A.3.3.1 and for FIELD 1 in A.3.3.3.

Information related to probes or to results of chemical analyses is included in the legend and operating status bars of plots used for time series analysis. For an in-depth explanation of the visualisation concept, the underlying colour scheme and an overview over additional abbreviations used in analysis plots, see Appendix A.

2.9.1.3 Metadata assigned to control units and data loggers, basic quality control

Control units and data loggers were used to synchronise the equipment (via online or offline time servers or by manual operation), as well as to define the measuring frequency and automatic probe cleaning settings for the connected probes.

Based on operational experience, in particular with short measuring intervals and multiple probes connected to a control unit, a set of basic criteria to check for proper operation was implemented in the *R* programming code.

This concept for basic quality control consists of two steps. In a first step, the widths of the measuring intervals were checked towards a defined target interval for the control unit during a trial. Measurements were categorised as *over* or *under* the target value, or *exactly matching* the value. While gaps exceeding the width of the target interval are usually caused by power outages or control unit deactivation due to maintenance efforts, intervals shorter than the target value are often an indicator for a measuring interval the control unit cannot handle. The second scenario is usually induced by the operation of too many probes, possibly in combination with demanding automatic cleaning settings.

The second step of basic quality control is aimed at the congruence of subsequent measurements of selected probes. Operational experience shows, that identical subsequent measurements over all parameters, of *spectro::lyser* probes in particular, are a clear indicator for a measuring interval that is too short for the operated equipment. Thus, a criterion was defined, stating that when comparing all parameters of two subsequent measurements, if the results of at least one parameter differ, the two measurements differ. If the results of all parameters of the two measurements are identical, they are considered *congruent*. When the number of congruent measurements rises, the configuration of the equipment should be reviewed and possibly altered.

Basic quality control is applied to *s::can* probes and turbidity probes of type *Solitax* by company *Hach Lange*. As all equipment was operated at the highest possible measuring frequency, the need for quality control in the form of flagging of dubious data accordingly became apparent. The visualisation of quality control information is included in the lowest two status bars of the time series plots generated for data analysis. Examples for the visualisation of quality control information are shown in Figure 2-29 and Figure 2-30.

Information on the control unit a probe is connected to, followed by the implemented measuring interval used during a trial in seconds, written in brackets, is part of the probe-specific legend elements of plots for result analysis and interpretation.

2.9.2 Time series visualisation and analysis

By merging metadata with monitoring results in the form of time series plots, a visual analysis and interpretation of behavioural patterns was possible. The plots combine all of the states and parameters predefined before in static figures, which can be reviewed in digital form in Appendix C. For these plots, time series of primary probes from laboratory experiments are combined by Trial ID, reactor name and (sum) parameter. Results from secondary probes are combined in a single plot, representing all parameters monitored in a reactor. The data from the two field testing programmes is divided in sections of approximately two weeks. Each of these sections visualises the results for all probes operated in a respective station at the time.

While the plots for the laboratory trials and the two field testing programmes differ in some nuances, the general colour scheme and plot layout is identical. All plots have a title, containing basic information on the trial, the reactor or the installation site and the time span, during which the trial was conducted. Another common feature is the legend, containing the relevant information on installed probes or chemically analysed grab samples. These legends, as exemplarily depicted in Figure 2-29 and Figure 2-30, have been simplified for the figures of chapter 3.

The main section of a time series plot contains a core element, depicting the time series of a parameter for one or multiple probes. In the graphical representation of the results from laboratory trials, the background shading of this section offers a distinction between the sub- or immersion media inside the reactors. This feature was not transferred to plots for field testing programmes, since probes for water level and flow rate detection were available at monitoring stations Graz-CST-CS1 and Graz-WWTP-CSO. The results of these probes are represented as separate time series, depicting water levels over time, as well as the station-specific submersion thresholds. A set of four operating-status-bars and two quality-control-bars are amended to the main part of a time series plot. Operating-status-bars contain probe data (e.g. automatic probe cleaning status) and reactor data (e.g. system manipulation, reactor agitation). Quality-control-bars use coloured tick marks to visualise the results of the basic quality control process of section 2.9.1.3.

Fictitious examples of two time series plots, as used for data analysis, are featured in Figure 2-29 and Figure 2-30. For a detailed overview of the visual representation of the results, the colour schemes and abbreviations see Appendix A, section A.2. There the layout, as well as additional features and minor structural differences are defined for laboratory and in-situ results.

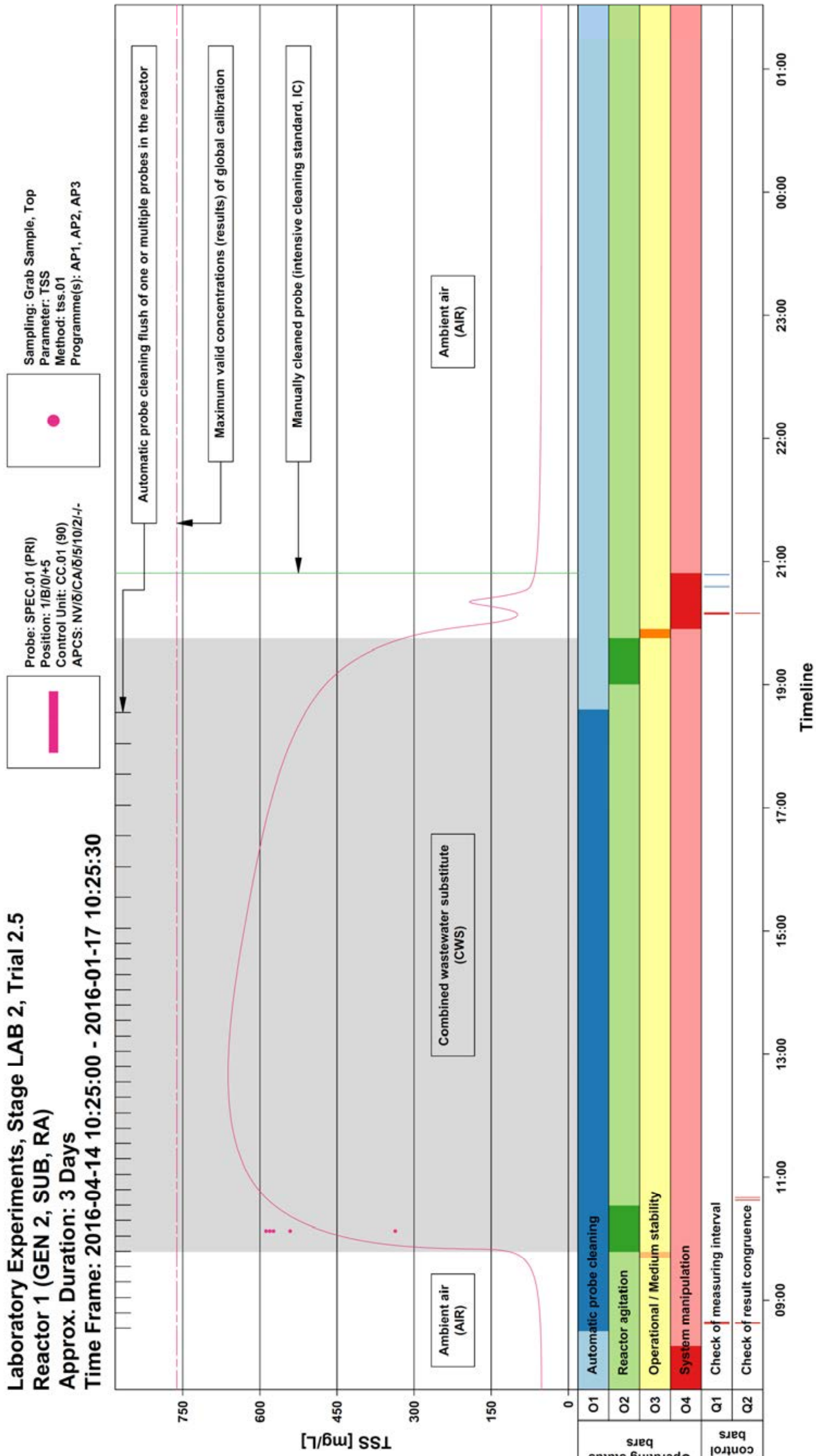

Figure 2-29: Example of time series visualisation for the analysis of laboratory data during LAB 2

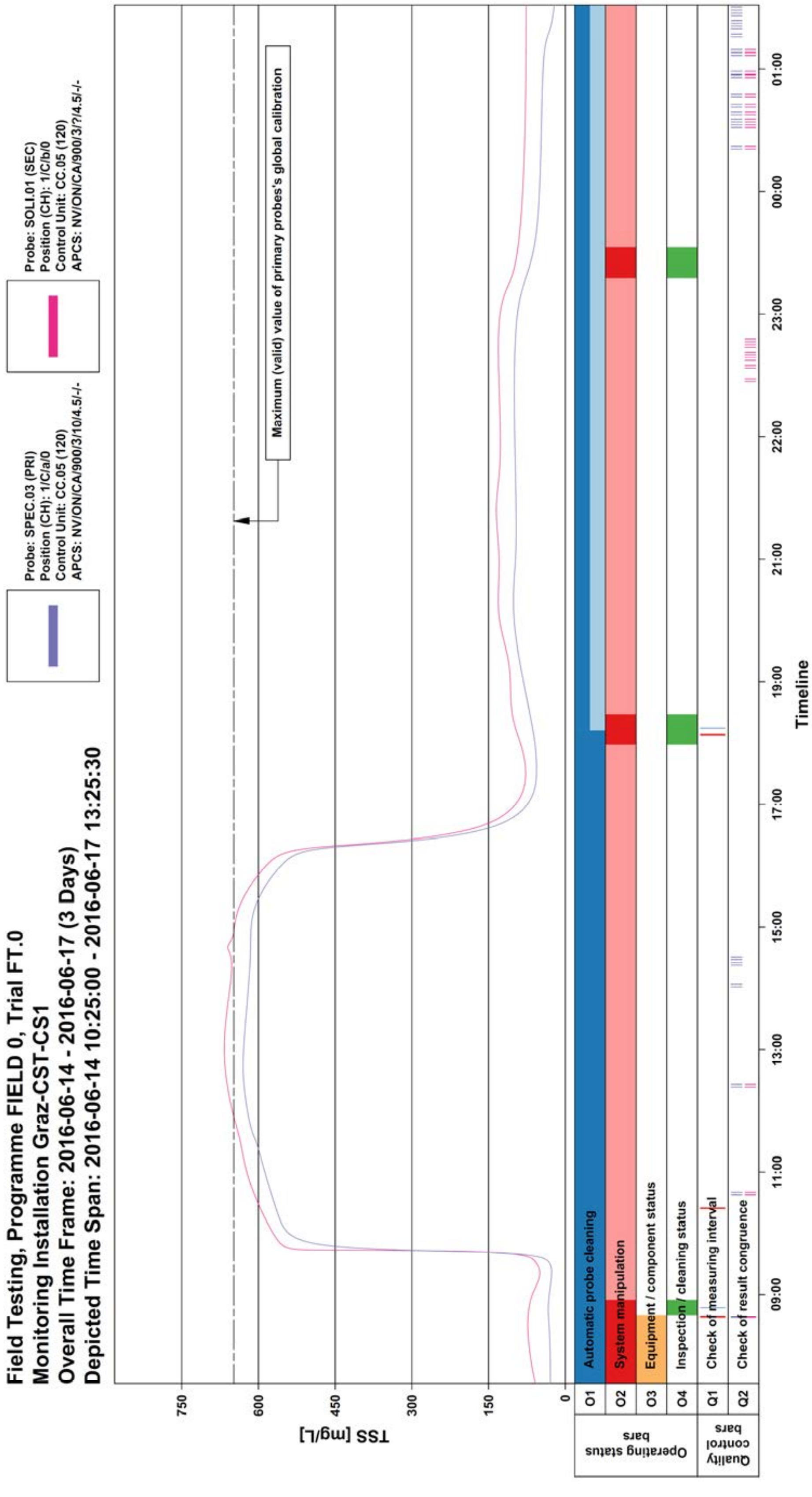

Figure 2-30: Example of time series visualisation for the analysis of results from the field during FIELD 0

2.9.3 Data interpretation for operational optimisation of spectrometer probes

Operation of spectrometer probes in the CST is understood as sequence of periods of submersion in combined wastewater and such of operation in the ambient air of the control structure CS 1. These periods are linked by periods of transition, during which the water level rises above or sinks below the sensors of the installed probes. This concept, as introduced in chapter 1.2, was not only used as basis for reactor design and planning of the laboratory experiments, but also for the analysis and interpretation of the generated data.

Although there are interdependencies between these periods, after a review of the results from laboratory and field trials, it seemed reasonable, to review these three operating states individually in a first step, before considering the implications one has on the others in a more integrated approach in a second step. The order of analysis was chosen as depicted in Figure 2-31.

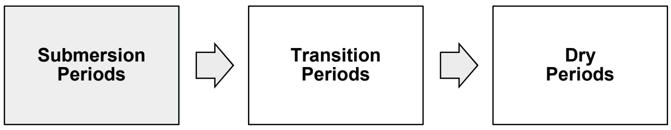

Figure 2-31: Compartmentalised operational periods for data analysis in order of consideration

At first, behavioural patterns during sub- or immersion periods were analysed and linked to their sources. Subsequent analysis was aimed at pinpointing patterns in the time series, which occur during transition periods, with focus on the transition from operation in CWW or CWS to operation in ambient air. Patterns occurring during dry operation of the probes were analysed afterwards.

As submersion periods are usually the periods of interest for operators of structures in a sewer system with periodical overflow or storage events, the time series of spectrometer probes during these phases were analysed with the goal of identifying patterns indicating interference from the equipment or deficiencies in a probes placement. In doing so, optimisation potential was identified and combined in a set of necessary changes to the spectrometer probe's installation and configuration, for the specific case of monitoring station Graz-CST-CS1. When interpreting the data from transition periods and subsequently evaluating dry periods, fouling behaviour of the spectrometer probes and therefore management or maintenance aspects were of particular interest.

After considering the characteristics in the three operational states individually, the interdependencies between them had been considered in an integrated analysis of a sequence of submersion and dry states, which overlap in the form of transition periods, as pictured in Figure 1-4. The goal of combining the findings of the individual analyses was to narrow down the reasons for negative probe behaviour in the CST in order to facilitate a set of a few, but highly effective changes to the existing installation and to the management concept for its equipment, with as little changes to the current monitoring station as possible.

3 Results, Discussion and Conclusions

Based on visual analysis of the time series and metadata from both, field and laboratory experiments, multiple characteristic patterns in the data of spectrometer probes, operated in systems with alternating submersion conditions, have been identified and linked to one or multiple aspects of these probe's placement, mounting system, configuration or management.

While an interdependency between the effects of submersion events and dry falling periods on the behaviour, and particularly the fouling of spectrometer probes exposed to the aforementioned conditions (chapter 1.2) was acknowledged, operational states were analysed individually, before the identified effects were interpreted in a more global context. Hence, in a first step the behaviour of spectrometer probes, given an exposition to the conditions and constraints encountered in the CST, was analysed individually for submersion, transition and dry periods, before combining and evaluating the findings in the context of a continuous sequence of these states in a second step. During this second step focus was placed on the possible consequences for long-term operation under alternating submersion conditions with little to no maintenance.

Integrated analysis of data from the inflexible installation Graz-CST-CS1, the flexible installation Graz-WWTP-CSO and the data from laboratory experiments allowed a distinction between characteristics in the time series which can be linked to particular forms of mounting systems, probe placement or installation types and others which can be attributed to the monitoring environment and the measuring medium, regardless of probe placement or orientation.

Since operators of spectrometer or in-line water quality probes in systems with temporary probe submersion as a result of alternating flow conditions are usually interested in submersion periods, e.g. storage or overflow events, this operational state was used to identify patterns of negative probe behaviour and link them to their source, with the intent of developing viable options to reduce feedback from the operational environment and the monitoring equipment on the generated data. Characteristic patterns in the time series of spectrometer probes during transition periods provided further information about the potential for adaptations of the configuration and installation in systems with alternating operating conditions. Even though probe behaviour during dry operation is not of interest for probe-operators when it comes to data collection, this operational state offered insights in fouling characteristics and showed potential for targeted maintenance planning. Finally, an in-depth analysis of the three operational states, taking into account the interdependencies between them, led to additional conclusions.

While only a number of negative behavioural patterns could be distinctly linked to specific conditions or configurations, it was possible to analyse them in detail, leading to cause-and-effect determinations, which can serve as a foundation for the implementation of measures to optimise probe operation at monitoring station Graz-CST-CS1. When implemented, this set of measures has the potential of increasing data quality during submersion periods and of significantly reducing the need for on-site maintenance.

3.1 Submerged or immersed state

Operators are interested in event duration, as well as the volume and composition of the waste or storm water passing a monitoring installation. Thus, it is imperative to avoid or at least minimise interference from the equipment on the generated data. Additionally, ideal probe placement and an adequate, site-specific mounting system play key roles in providing high-quality and high-resolution data during these events.

The current placement, installation and configuration of the monitoring equipment in the CST provokes negative probe behaviour during submersion periods, as shown by results from both field testing programmes and supplemented by data from the laboratory experiments. The most crucial of those negative characteristics are listed and discussed in this chapter with a focus on spectrometer probes. The elimination of the majority of these negative effects only requires small modifications to the mounting system and equipment configuration of the existing installation, while being exponentially harder to eliminate from the time series, once the data is generated.

The proposed solutions are all based on the requirement by the operator of the CST that changes to the installation currently in place, have to be limited to a minimum. In addition to increasing the quality of the time series generated with spectrometer probes during submersion periods, an optimised installation design could also reduce probe fouling between storage events by minimising susceptibility to clogging and curtailing run-off over the measurement window, thereby reducing maintenance efforts considerably. While the following patterns are described individually, most of them are enhanced by a combination of suboptimal installation, configuration and management of the probes. Therefore, a single change can not only reduce one negative effect, but entail an overall increase in performance for specific probes or entire monitoring installations.

3.1.1 Sediment accumulation in the measurement window of spectrometer probes

This *sediment-accumulation-pattern* is characteristic for vertically installed spectrometer probes in inflexible mounting systems in combined wastewater, when there is limited or no flow around the equipment. Another factor in promoting this effect is a lack of automatic probe cleaning or insufficient pressure of the cleaning medium (e.g. compressed air).

Figure 3-1: Sediment at the bottom of a GEN 2-reactor (left), on the equipment (middle) and around the measurement window of a spectrometer probe (right)

During LAB 1 and LAB 2 and therefore for both generations of reactors, sedimentation on the bottom window of the optical measuring path of spectrometer probes (Figure 3-1, right) started as soon reactor agitation stopped. The measured pollutant concentrations seemed to be stable during agitation periods, regardless of the type of agitation system, as stirring was used during LAB 1 and reactor aeration during LAB 2. Similar patterns can be identified in time series from spectrometer operation in the CST, where periods of insufficient or no automatic probe cleaning occurred due to inadequate compressor performance. The horizontally installed spectrometer probe in the highly dynamic environment during FIELD 1 did not exhibit this pattern.

Even though there is a significant difference in reactor volume and probe combinations between the experiments of LAB 1 and those of LAB 2, no relevant difference in the sedimentation ratios in the measurement window of the installed spectrometer probes was observed. There was no obvious indicator, which would suggest a significant influence of the size of the measurement window (2 mm and 5 mm) on the accumulation of residue. The comparable sedimentation characteristics in the measurement windows in the laboratory and in the CST, can be attributed to the inclination of the installed probes. Furthermore, the similarities in the sedimentation patterns are a testament to the accuracy of the CWS samples used in the laboratory, in emulating the combined wastewater encountered in the field.

The data suggests that the observed form of sediment accumulation in the measurement window of spectrometer probes is significantly different in its developmental characteristics then *real* sedimentation in the laboratory reactors (Figure 3-1, left and middle) or the operational environment in the CST. Particle accumulation in the measurement window of the vertically installed spectrometer probe of the current monitoring installation of the CST presented itself as depicted in Figure 3-2 [1] and could be linked to insufficient automatic probe cleaning during storage events (Figure 3-2 [2]).

The configurations and constraints leading to this behaviour were successfully replicated in the laboratory setups of LAB 1 and LAB 2, as shown in Figure 3-3. While the limitations of the laboratory setup did not allow testing of automatic probe cleaning with compressed air pressures exceeding 2.5 bar, the resulting data, in combination with time series from both field testing programmes, suggests a high cleaning pressure, at the 8 bar limit proposed by the manufacturer (s::can Messtechnik GmbH, 2007, 2011), in combination with a short interval between the cleaning flushes, would be the best solution to avoid sedimentation in the measurement window in general (as becomes obvious when comparing Figure 3-19 and Figure 3-20) and between cleaning flushes (Figure 3-6).

The generated data also suggests, that in order to monitor real sedimentation in the operating environment, the inclination of spectrometer probes would have to be changed, ideally leading to a horizontal installation, substantiating requirements in the probe manuals (s::can Messtechnik GmbH, 2007, 2011).

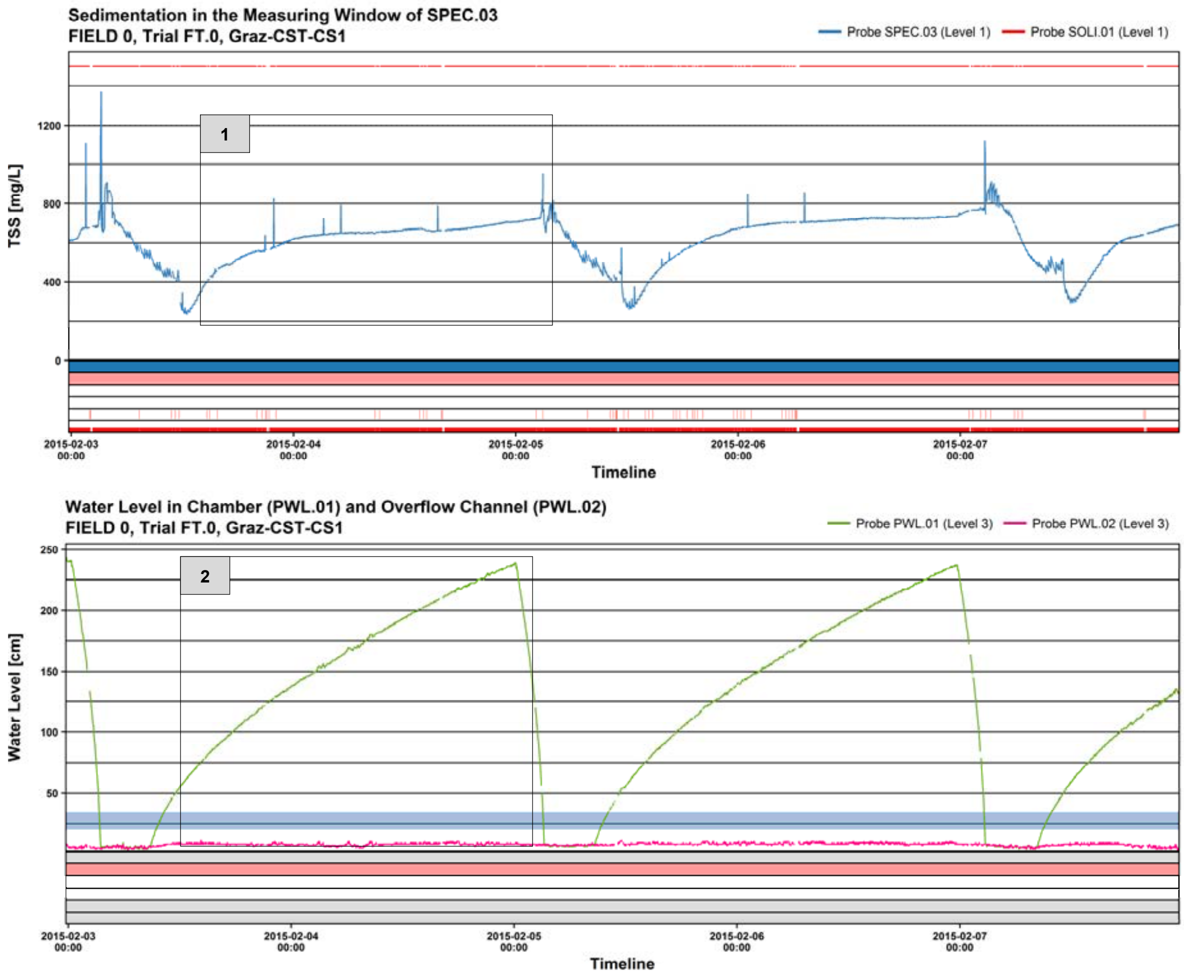

Figure 3-2: Sedimentation in the measurement window during Trial FT.0 of FIELD 0

While sedimentation in the measurement window seemed to distort the resulting concentrations of solids and carbons significantly, the residue seemed to be washed off easily not only by automatic probe cleaning, but by a sufficient flow during the transition between submersion and dry periods. Figure 3-3 [1] highlights the formation of a sediment layer in the measurement windows of two spectrometer probes as a consequence of insufficient or in this case, no automatic probe cleaning and limited dynamics in the operational environment during probe submersion (grey backgrounds). As a result, an invalid TSS concentration, which increases continuously, was measured during the highlighted submersion period. As a consequence, plaque is formed and an increase in the basis TSS concentration after the submersion event can be observed, if the probe is not cleaned manually, as is the case in Figure 3-3 [2]. Differences in the sediment accumulation patterns in the optical path in the top and the bottom charts of Figure 3-3 are attributed to slight differences in the inclination of the probes and thereby of their measurement windows. As the probes were installed in separate reactors, there might have also been minimal differences in CWS-sample-composition. During the agitation period in the reactor, accumulated particles are washed off the measurement windows as a result of the flow and turbulences in the reactor, marked in Figure 3-3 [3].

But, as the development of the base line in Figure 3-3 [2] suggests, this effect is not pronounced enough to remove all sediment particles from the measurement window.

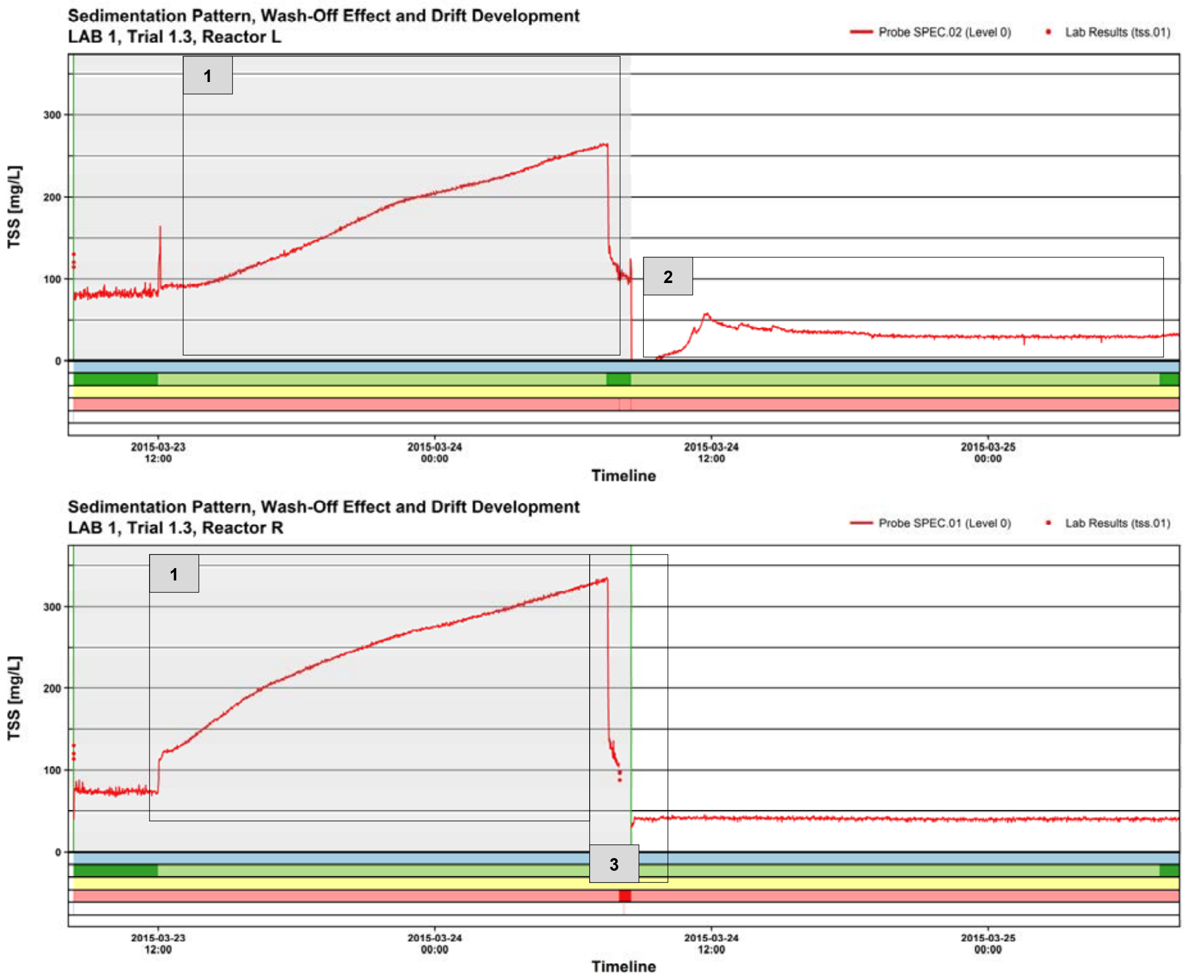

Figure 3-3: Sedimentation in the measurement window, drift and shift pattern during Trial 1.3 of LAB 1

A variation of the sediment-accumulation-effect, when sufficient cleaning pressure is provided, but the inclination of the probe is sub-optimal and/or the frequency of the cleaning flushes is too low, is depicted in Figure 3-4. The combination of these constraints enables sedimentation on the lower window of the measuring path between cleaning flushes, as highlighted in Figure 3-4 [1] and Figure 3-4 [2]. In the top of the two charts of this figure, TSS and COD time series of a spectrometer probe are shown. The frequency of the automatic probe cleaning flushes is varied over time, given otherwise identical operating conditions. Cleaning flushes are marked with ticks at the top of the three depicted time series charts in the figure and highlighted by the dissolved oxygen concentration in the bottom chart.

Summarizing the findings above: A proper configuration of the automatic cleaning features avoids sedimentation in the measurement window of spectrometer probes. As a consequence, a more accurate time series is produced. This is of particular importance when the probe is installed vertically.

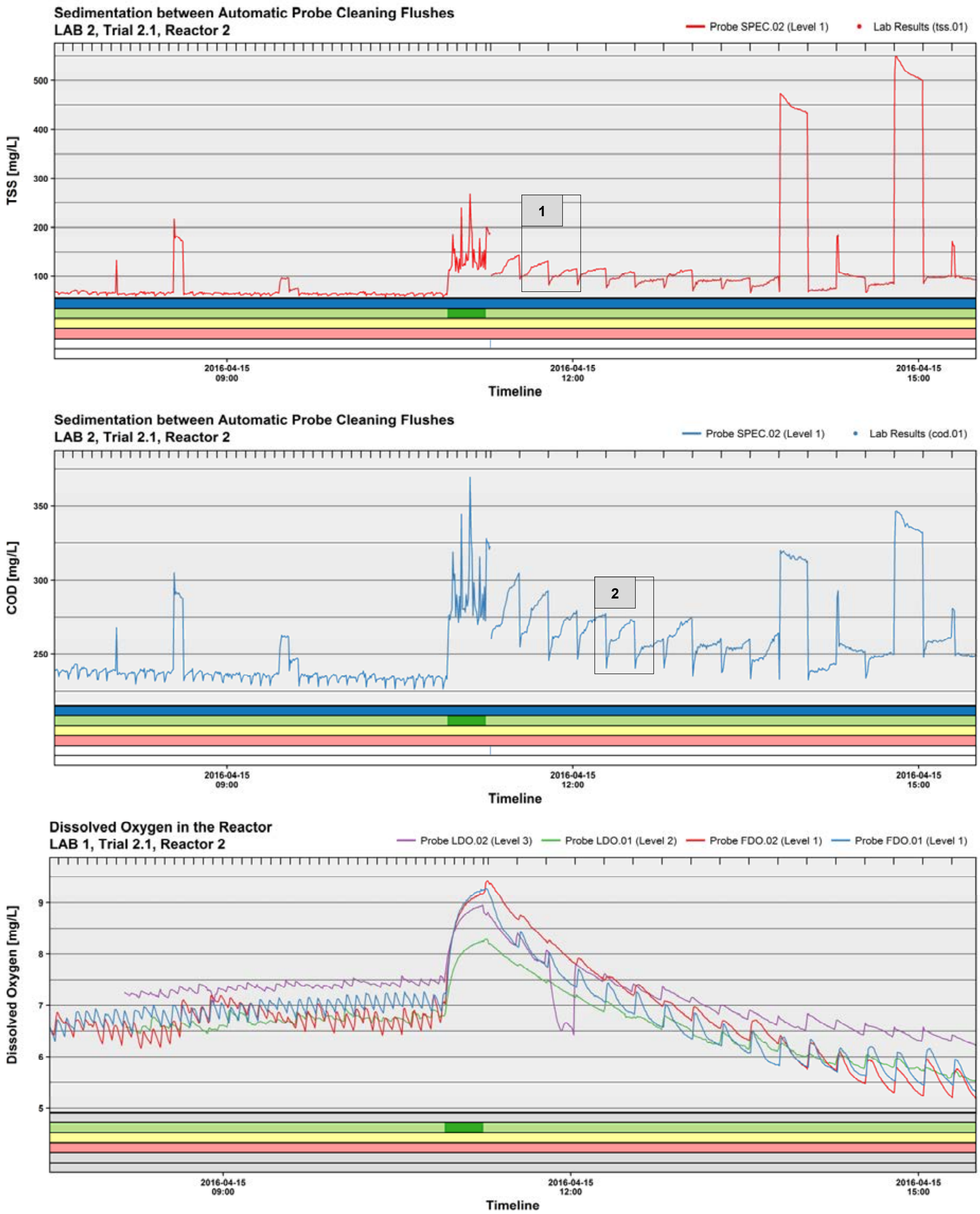

Figure 3-4: Sedimentation in the measurement window between automatic probe cleaning flushes during Trial 2.1 of LAB 2

3.1.2 Wash-Off of residue or plaque from the measurement window of spectrometer probes

There are two aspects to this *Wash-Off* effect, which occur during two different points in time during the operation of temporarily dry falling spectrometer probes in combined wastewater. Though they are observed in different operational situations, the effects show similar characteristics. Thus, they have been bundled in this chapter. This Wash-Off pattern is not exclusively linked to vertically installed spectrometer probes, since forms of it were observed during all trials with all used installation types.

A wash-off effect can be observed at the beginning of agitation periods in the laboratory, in particular, but not uniquely, after sedimentation periods, as described briefly and depicted (Figure 3-4 [3]) in the previous chapter. While this first type of Wash-Off occurs during probe submersion in the laboratory only, a very similar effect can be observed in the field, when plaque is removed from the measurement window of spectrometer probes, as highlighted in Figure 3-5 [1], by a stream of CWW during the submersion events marked in Figure 3-5 [2].

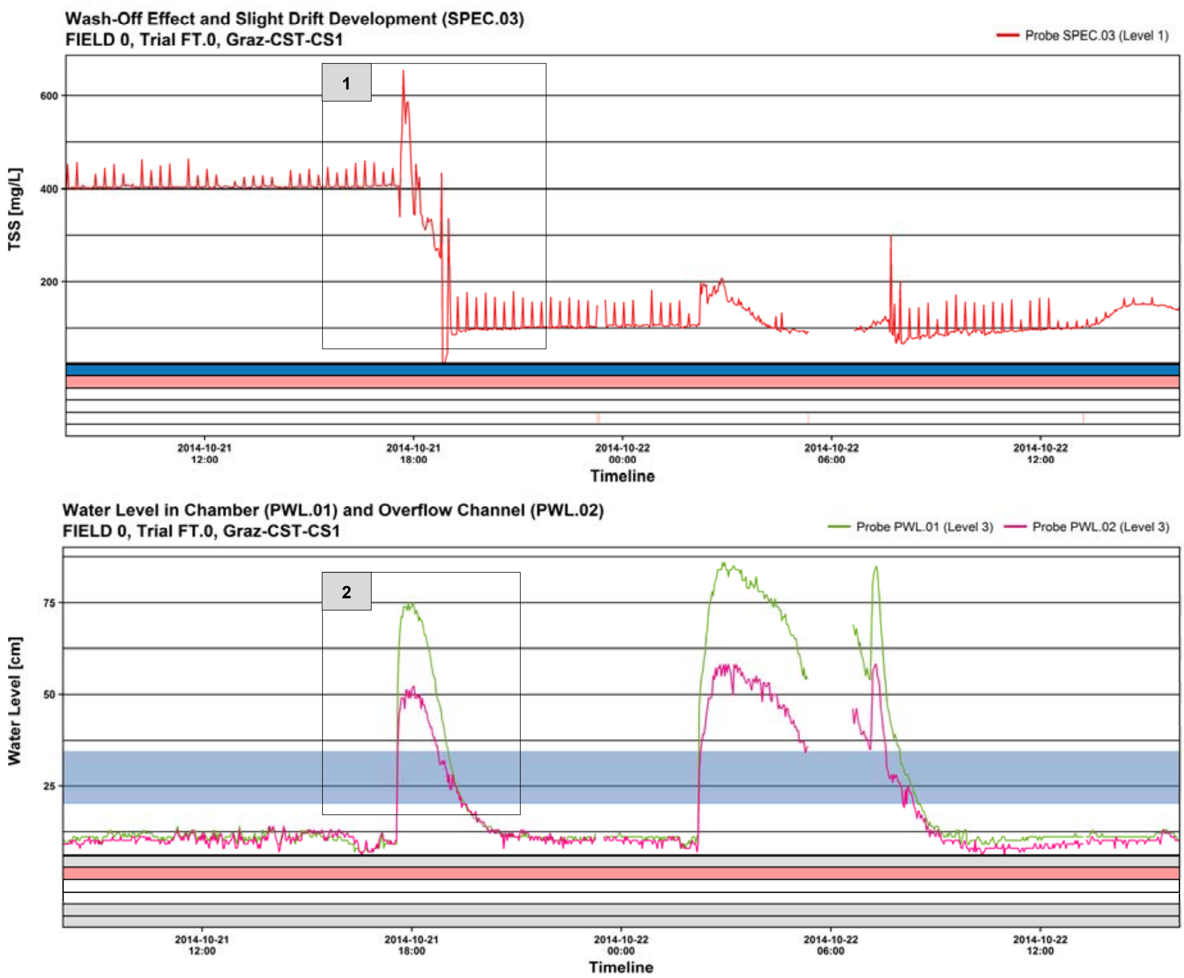

Figure 3-5: Wash-Off phenomenon (self-cleaning) as a result of probe submersion during Trial FT.0 of FIELD 0

Figure 3-6 paints a more detailed picture of this effect for an in-line installation exposed to a continuous sequence of submersion events with intermittent dry periods, for the case of monitoring installation Graz-WWTP-CSO during FIELD 1. In this case, most of the residue from a preceding submersion period (not depicted), causing higher concentration base lines for sum parameters TSS and COD was washed off, once the combined wastewater of the next overflow event reached the measurement window of the spectrometer probe with sufficient force (Figure 3-6 [1]). The base lines stayed at lower concentration levels, even as an additional overflow event took place (Figure 3-6 [2]), before there was another shift in the data, after residue accumulation in the measurement window occurs, as a consequence of sloppy manual cleaning (Figure 3-6 [3]). Cleaning agents and distilled water from probe maintenance lead to particle accumulation in the measurement window.

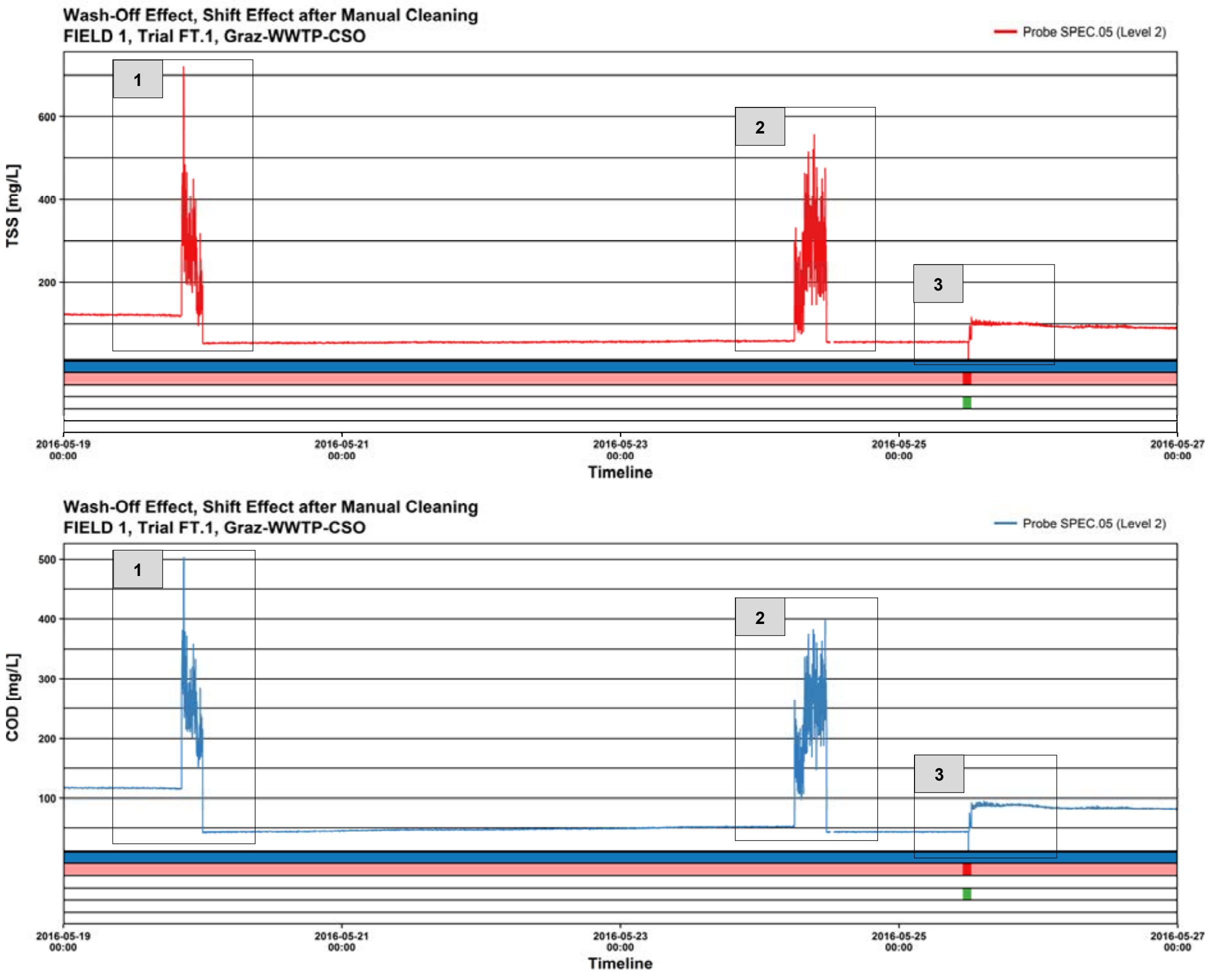

Figure 3-6: Wash-Off phenomena and shift due to inaccurate manual cleaning during Trial FT.1 of FIELD 1

A second form of *Wash-Off* was observed for the spectrometer probe of monitoring station Graz-CST-CS1 during storage events in the course of the trial programme during FIELD 0 in the CST. The TSS base concentration of spectrometer probe SPEC.03 highlighted in Figure 3-7 [1] is lowered considerably to the level shown in Figure 3-7 [2] in the course of a storage period (Figure 3-7 [3]).

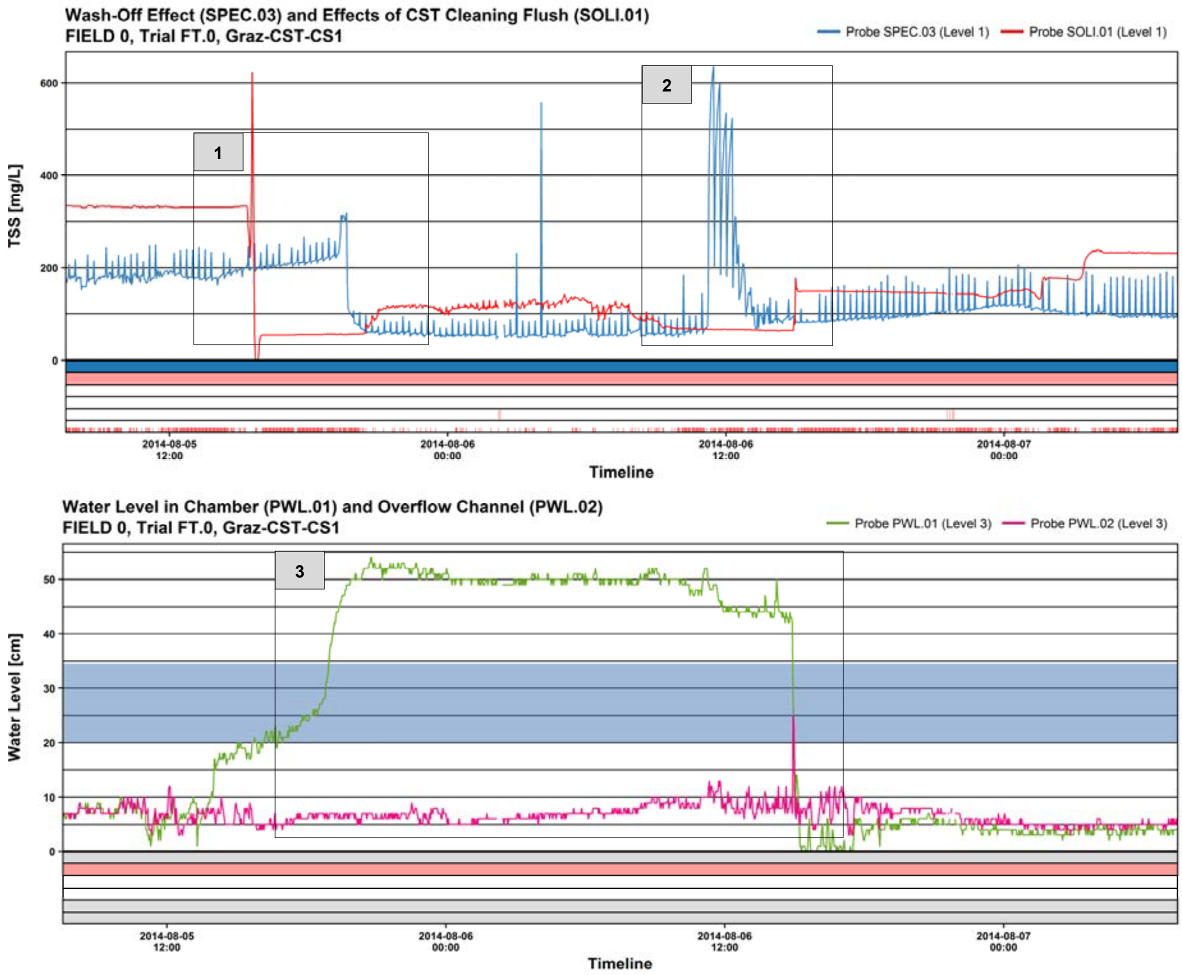

Figure 3-7: Wash-Off phenomenon, cleaning wave residue on probe SOLI.01 during Trial FT.0 of FIELD 0

The first form of Wash-Off, encountered in the laboratory, as well as the second form, encountered in the field become less pronounced with increasing probe fouling and might stop working entirely once a certain degree of encrustation in the measurement window of spectrometer probes is reached. Nevertheless, the positive aspects of the Wash-Off can be harnessed by using flexible mounting systems and ensuring a sufficient flow around the spectrometer probes, while still providing sufficient clogging prevention.

3.1.3 Plateau-and-Valley pattern in the time series of spectrometer probes

As a result of entrapped air bubbles in the measurement window, artificially elevated or reduced pollutant concentrations are measured by spectrometer probes, creating a sequence of plateaus and valleys in the generated time series.

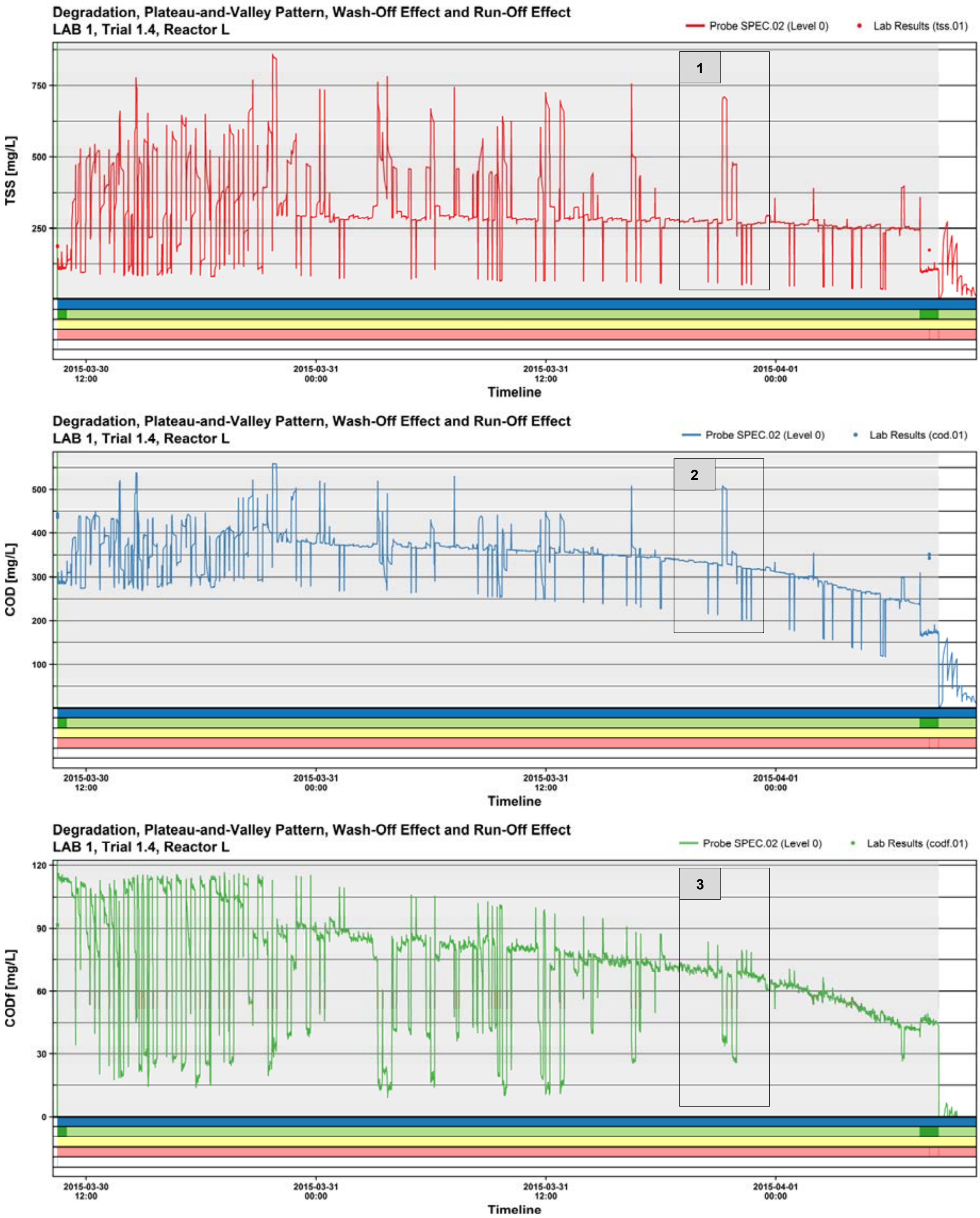

Figure 3-8: Plateau-and-Valley pattern due to air bubbles in the measurement window and degradation in GEN 1-reactors during Trial 1.4 of LAB 1

The risk for the interfrence of air bubbles in the generation of valid spectra is mentioned in Brito et al. (2014) and the effects of entrapped or passing air bubbles on optical probes are described to some extent in Schilperoort (2011). Form and extent of this pattern depend on a series of factors, with the inclination of the probe, the flow in the measuring medium, the mounting system and the configuration of the automatic cleaning settings having the most influence.

The series of plateaus and valleys in the time series was particularly pronounced during LAB 1 and could also be identified clearly during LAB 2. It was no issue of particular consideration during FIELD 0 and did not occur with the monitoring installation of FIELD 1. This fact suggests, that sufficient dynamics in the operational environment, which can originate from an adequate mounting system as well as from the submersion medium, are a key aspect in avoiding this pattern.

While *real* concentration surges or declines detected by spectrometer probes, usually show an increase or decrease over all monitored parameters, the amplitudes of the plateaus or valleys induced by air bubbles entrapped in the measurement window (Figure 3-9 [1] and Figure 3-9 [2]) are oriented in a specific direction, based on the position of the wavelengths which are used to calculate a parameter on the light spectrum.

For instance, equivalent concentrations for TSS or COD were increased by entrapped air bubbles, resulting in plateaus in the time series, as marked in Figure 3-8 [1] and Figure 3-8 [2], while resulting in valleys in the time series for CODf concentrations, highlighted in Figure 3-8 [3]. Additionally, degradation effects in the medium are visible for all three parameters in Figure 3-8, likely induced by the 48-hour-duration of the depicted submersion period.

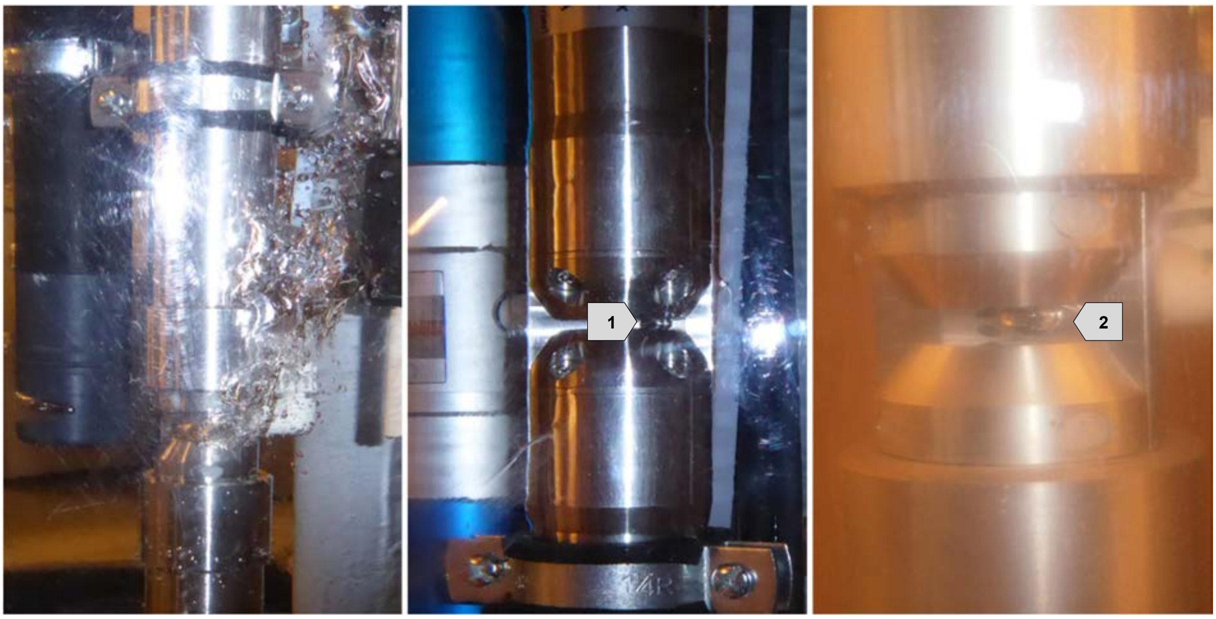

Figure 3-9: Automatic cleaning flush (left) and entrapped air bubbles in tap water [1] and in CWS [2]

Another key aspect in detecting this pattern is the fact that these plateaus and valleys occur with regularity, corresponding to the defined automatic probe cleaning interval, in contrast to actual short-time changes in the concentrations of the measuring medium.

Highlighted sections Figure 3-11 [1] through Figure 3-11 [4] show variations of the Plateau-and-Valley pattern in greater detail. During the second stage of laboratory trials more metadata was collected in combination with the use of dissolved oxygen probes and turbidity probes, to distinguish between actual surges in pollutant concentrations and those induced by entrapped air bubbles below the top window of the optical measuring path. By combining data from e.g. dissolved oxygen probes (Figure 3-11, bottom chart) and sedimentation probes with the documentation of automatic probe cleaning flushes (tick marks at the top of the charts in Figure 3-11) this distinction could be made successfully.

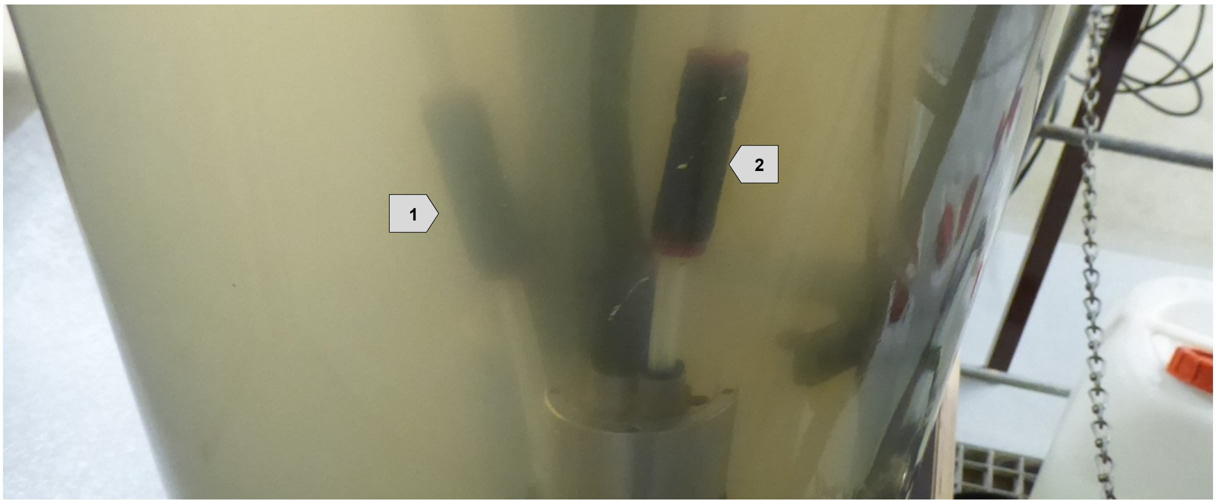

Figure 3-10: Check valves [1] and [2] installed in the compressed air lining of spectrometer probes during LAB 2

An on-site solution for avoiding this particular behavioural pattern is necessary, as characteristics of the resulting effect vary with the interval for automatic probe cleaning, the duration and intensity of the automatic cleaning flushes and the number of installed, simultaneously cleaned probes in the vicinity of the spectrometer probe of interest.

As the data suggests and depending on the parameter and its position on the UV-VIS spectrum falsified concentration levels are either plateaus *or* valleys. Without extensive knowledge of this behaviour in combination with information about the activated global calibration and a possible local calibration regiment, as well as at least a general idea of the automatic probe cleaning configuration of the equipment, adapting and smoothing of the time series to remove plateaus and valleys is almost impossible in post-processing.

Compared to the required efforts for modifying the data after the fact, a small set of changes to the installation might prevent the occurrence of this pattern. By not installing the probe entirely vertically, using check valves (Figure 3-10 [1] and Figure 3-10 [2]) to hinder the infiltration of capillary water in the compressed air lining, in addition to applying maximum compressor pressure and cleaning frequency for automatic cleaning, the negative behaviour can be reduced. Check valves in the compressed air lining in close proximity to the connector of the probes were tested during LAB 2 and led to a reduction of plateaus and valleys in the time series.

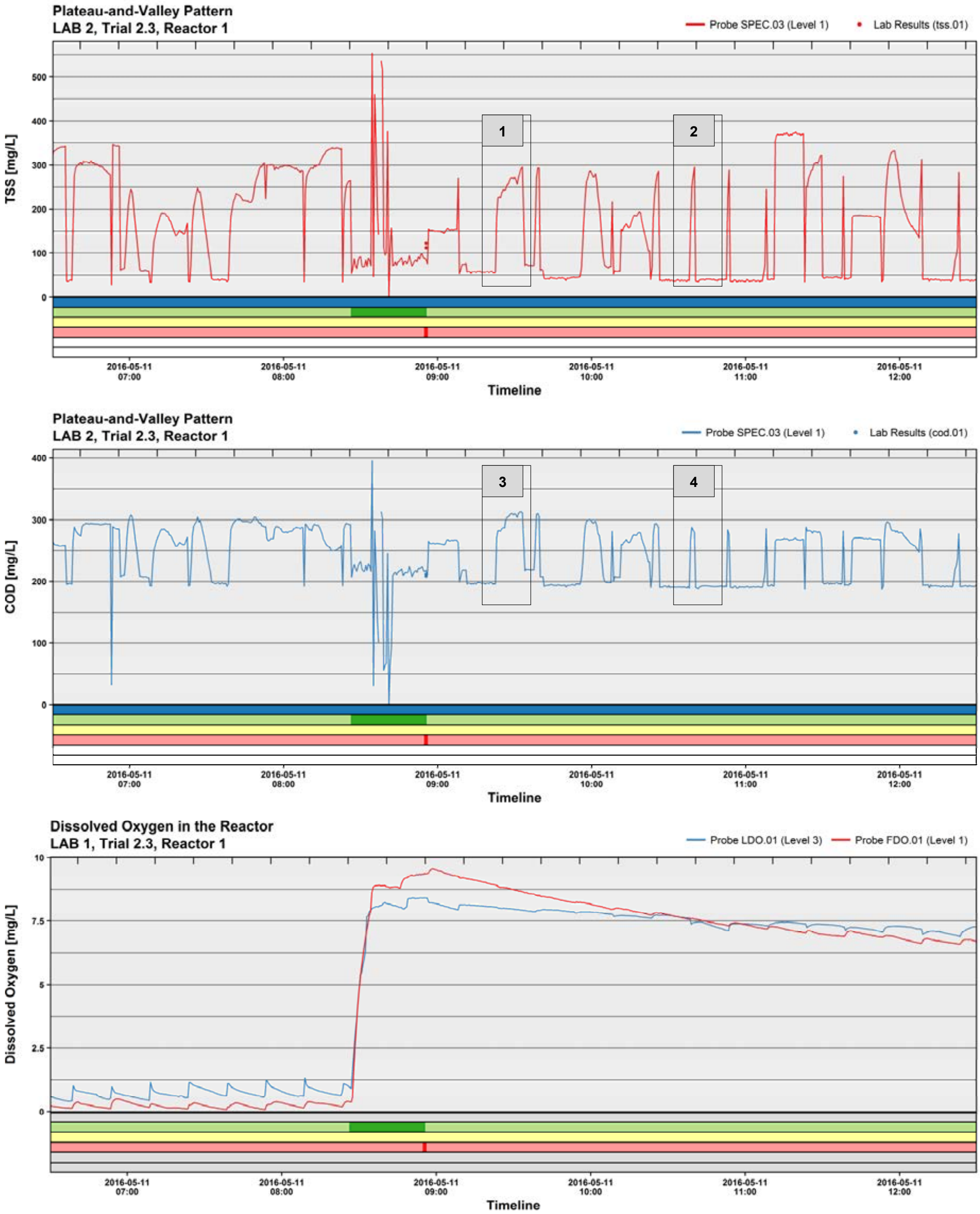

Figure 3-11: Detailed representation of the Plateau-and-Valley pattern during Trial 2.3 of LAB 2

Further damping of the effect can be achieved by ensuring a sufficient flow around the probe during submersion. The lack of this behaviour with the high dynamics of the medium and the floating pontoon during FIELD 1 seems to corroborate the effectiveness of the proposed measures.

3.1.4 Conclusions for operational optimisation in the submersion state

The patterns and behavioural characteristics identified in the course of laboratory and field trials were consolidated in a series of possible changes to the monitoring station in the CST. While the following conclusions are derived from tests with the intent of optimising the installation of Graz-CST-CS1 they are universally applicable for the in-line operation of spectrometer probes in systems with similar, alternating submersion conditions.

The current installation in the CST seems to implicate significant potential for negative behaviour during probe submersion. Modifications to the mounting system are imperative before the start of long-term operation of Graz-CST-CS1. Under the assumption that no major changes to the current monitoring system are possible, thus preventing a possible transition to a flexible installation similar to the pontoon of station Graz-WWTP-CSO or a different placement of the probes, only the following, but nonetheless highly effective set of changes could be realised.

The enclosed environment behind the existing sheet metal cover (Figure 1-5) seems to encourage probe fouling and increase drift behaviour of probe SOLI.01, an optical probe of type *soli::lyser* by *s::can*. Hence, a perforated cover seems to be suited better. Not only would it increase the flow dynamics of the measuring medium during submersion events around all probes, while still offering sufficient clogging prevention, it would also avoid the two-level-shift in the time series of the *soli::lyser* probe (section 3.2.2), as the flushing waves in the CST (Maier, 2014) would not be reflected as strongly.

To increase comparability of the generated data, the sensors of all probes behind the sheet metal cover should be placed at the same level.

The vertical installation of the spectrometer probe is sub-optimal regarding the entrapment of air bubbles and sedimentation in the measurement window. Hence, the inclination of the probe should be increased considerably. If sedimentation in the CST during storage periods is of interest, the probe should be installed horizontally.

Automatic probe cleaning intervals should be reduced considerably and the compressed air pressure increased, ideally in combination with the installation of a check valve before the probe's compressed air lining connector. Due to the considerable length of the compressed air lining between the compressor in the control room above CS 1 and the in-line probes in the chamber of the control structure (approximately 10 metres), which is, beyond that, split to serve another installation in the overflow channel adjacent to the structure, it is recommended to add another magnetic valve to trigger compressed air flushes to the control unit of station Graz-CST-CS1. With the two magnetic valves probes of the two installations at CS 1, can be automatically cleaned in series. In doing so, adequate cleaning pressure is ensured at both installations. The implementation of sequential automatic cleaning might require a reduction of the measuring frequency to avoid problems with the triggering of measurements, the storing of results or overlaps between cleaning flushes and measurements.

3.2 Transition state

The transition state in the operation of in-line probes exposed to the alternating conditions of the CST includes unstable periods during the rising and falling of the water level, in particular with respect to the measurement window of spectrometer probes. The effects observed during periods of transition in the laboratory and in the field, are similar to the effects described in the previous section, highly dependent on probe placement, probe configuration and the applied mounting system.

Even though instability in the time series occurs at the beginning of submersion periods as well, most characteristic patterns can be found during the transition from submersion to dry periods. These transitions can impact probe fouling significantly, as residue and clogging materials are either washed off or held back, as the sinking water level passes the measurement window of spectrometer probes or the sensors of other probes. As soon as left-behind materials become durable encrustations, probes inevitably require maintenance on site. In case this maintenance does not take place, probe accuracy during the following submersion periods has to be considered insufficient. Assuming Wash-Off, as described in section 3.1.2 takes place, accuracy of the results might increase with the duration of the submersion periods.

Clogging of spectrometer or other in-line probes, which usually occurs and gets detectable during transition periods, is not a point of consideration in this chapter, as it was already mentioned in the previous one. Furthermore, it is considered a minimum requirement of any in-line installation in sewers to ensure clogging of the installed equipment with debris or hygiene products cannot take place.

In contrast to the identified negative behavioural characteristics of vertically installed spectrometer probes during submersion periods, the following effects do not immediately lead to deprecated measurement results. Nonetheless, they can have a significant impact on long-term reliability of the generated data.

3.2.1 Run-Off pattern during transition periods

Even though this pattern was observed during all laboratory experiments and field trials, suggesting it being inherent to *spectro::lyser* probes with compressed air cleaning, it was particularly pronounced during FIELD 0 and the laboratory experiments. The mounting systems and vertical installation in these cases lead to a particular *Blow-Off* or *Run-Off* from the probes and their mounts during the transition between submersion and dry periods. While this behaviour became especially obvious during FIELD 0, LAB 1 and LAB 2, gaps between the cladding tube and the spectrometer probe at the bottom of the floating pontoon during field testing programme FIELD 1 caused a similar, but less distinctive pattern.

An example of the pattern, occurring after the end of a submersion period (grey background), is presented in Figure 3-11 [2]. This phenomenon only poses a problem, if the run-off leads to residue accumulation in the optical measurement window, inducing plaque formation. This consequence can be avoided by increasing the inclination of the probe in case of a vertical installation to accelerate run-off from the mounting system. Regardless of a spectrometer probe's inclination, an increase in frequency and automatic probe cleaning pressure seems to avoid most negative results, as run-off is removed before resilient plaque can be formed. In Figure 3-12 [4] the Run-Off pattern of Figure 3-12 [2] does not occur in the time series of Reactor R, since the probe was cleaned manually (indicated by the vertical green line) and dried off accordingly. Thus, no run-off from the probe could take place.

Figure 3-12 [1] and Figure 3-12 [3] show a concentration surge, typical for the small-scale GEN 1-reactors, at the beginning of agitation periods, as sediment particles rise from the bottom, before the composition of the sample in the reactors equilibrates itself. Additionally, the surge at the beginning of the agitation process in the marked sections is accompanied by a wash-off of sediment from the measurement window according to the description in section 3.1.2.

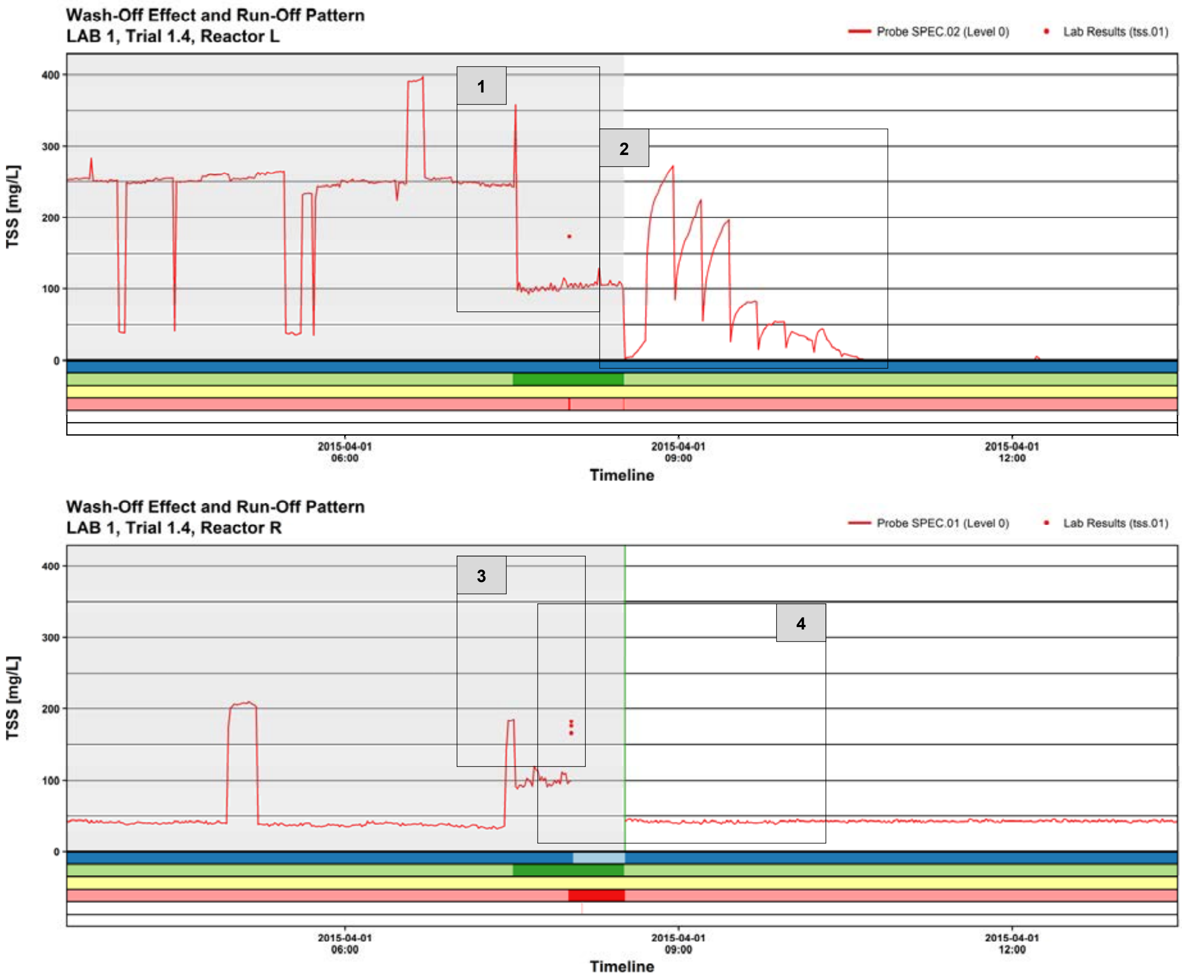

Figure 3-12: Wash-Off and Run-Off pattern during Trial 1.4 of LAB 1

3.2.2 Two-level-shift in the time series of secondary optical probes

Although the optical *soli::lyser* probe SOLI.01 of monitoring station Graz-CST-CS1 is not classified as primary probe it shows as specific characteristic a *two-level-shift* pattern, which is caused by the cleaning process of the CST after storage periods by way of flushing waves. During this cleaning procedure a wave of river water flushes downstream the storage tunnel (Maier, 2014), before being reflected at its end by the walls and weirs of control structure CS 1 and the sheet metal cover in front of the water quality probes in the storage chamber.

The reflection of the cleaning waves results in a two-level-shift pattern in the time series of the *soli::lyser* probe, as depicted in Figure 3-13 [1]. That occurs while spectrometer probe SPEC.03 is no longer immersed (Figure 3-13 [2]). This effect can only be removed by changes to the sheet metal cover, as described in chapter 3.1.4. Furthermore, it is a testament for the importance of probe placement and a minimum distance between the sensors of a probe and the CWW surface in the system during transition and dry periods to prevent probe fouling.

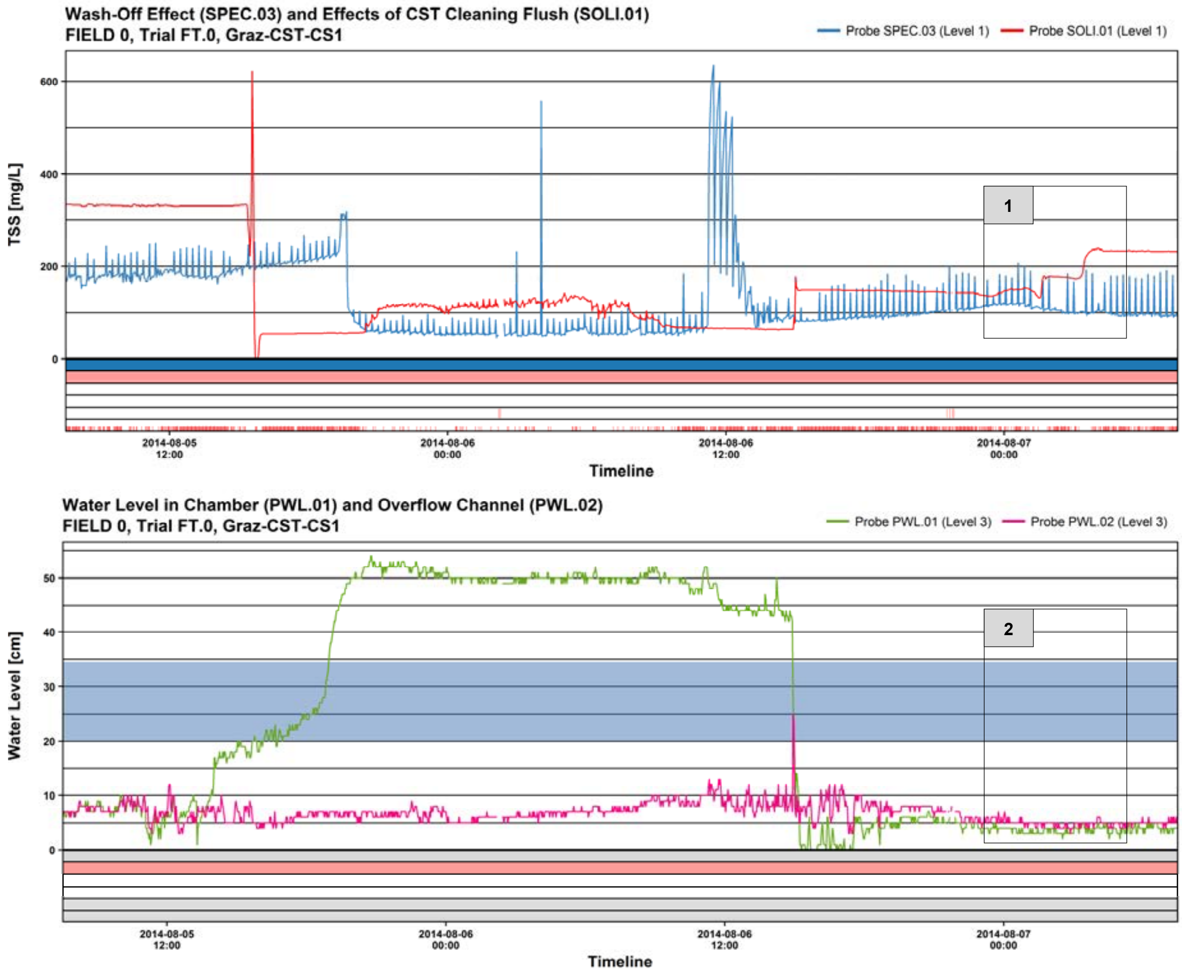

Figure 3-13: Two-level-shift due to flushing waves of the CST during Trial FT.0 of FIELD 0

3.2.3 Effects of a prolonged transition period, worst-case scenario

To test the effects of a possible prolonged transition between submerged and dry operation of spectrometer probes in the CST Trial 1.8 was conducted. This trial is intended to emulate a worst-case scenario for fouling of a vertically installed spectrometer probe during a dry period when the transition period is extended considerably, while no clogging of the measurement window occurs. This scenario was thought of, since no drift or permanent fouling of the probes occurred during the first seven trials of LAB 1.

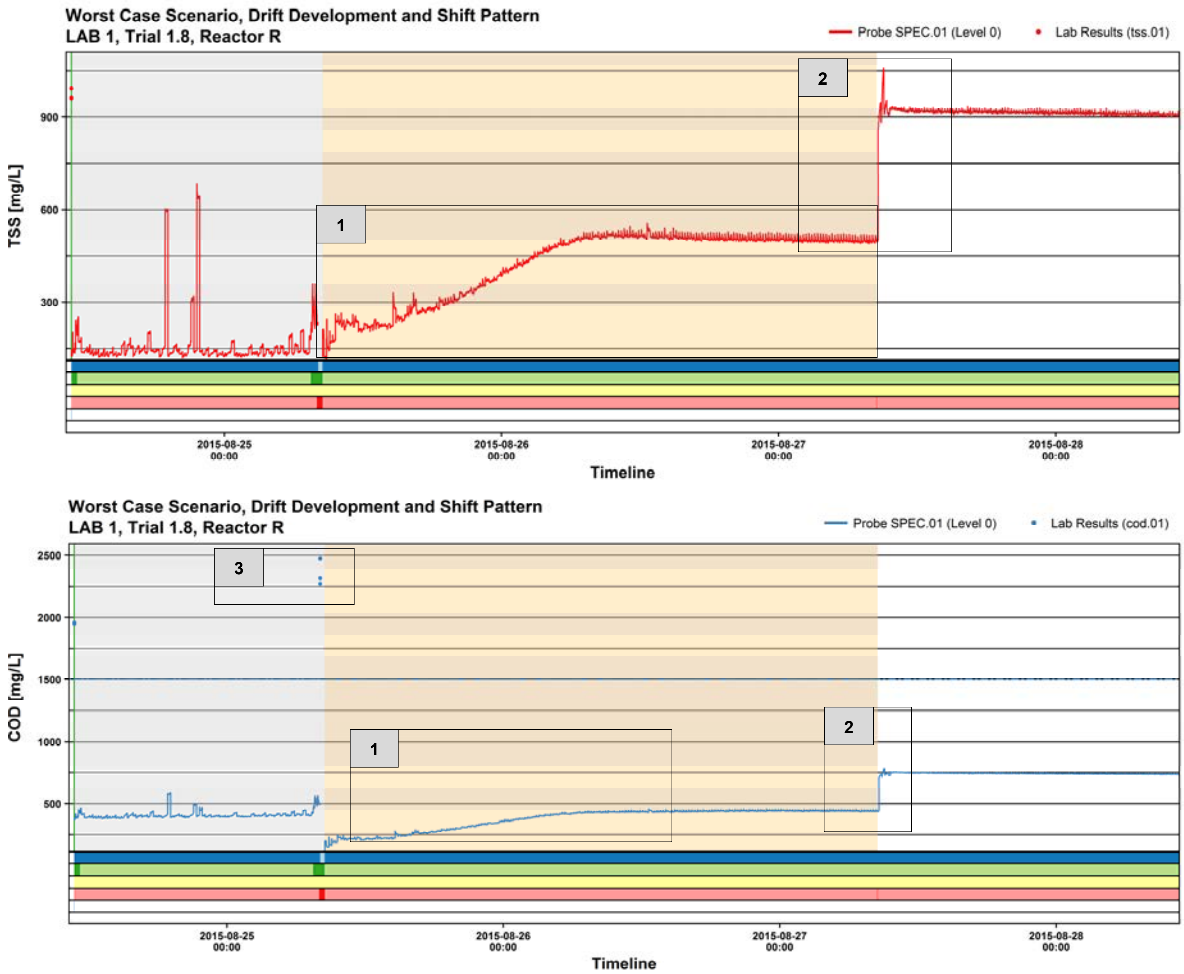

Figure 3-14: Forced probe fouling during Trial 1.8 of LAB 1

Based on data fragments from the test run at the CST, where permanent fouling was only observed after an extensive period without on-site maintenance, as depicted in Figure 3-27, plaque formation in the laboratory was forced by immersion of the spectrometer probe just up to the lower surface of the measurement window, while automatic probe cleaning was activated for 48 hours (orange background), after a 24-hour-long submersion period (grey background). The result was drift development via plaque formation during the 48-hour period in Figure 3-14 [1], followed by the instant shift pattern in Figure 3-14 [2], once the probe was placed in ambient air (white background).

For permanent fouling of spectrometer probes to develop in systems with combined wastewater and sufficient flow in the medium during submersion and transition periods, high concentrations of pollutants and possibly solids are required, as highlighted by the high COD concentrations in Figure 3-14 [3]. And even then, probe fouling is only induced and accelerated by wrong probe placement or sub-optimal probe configuration.

3.2.4 Conclusions for operational optimisation during transition periods

Negative effects in the behaviour of spectrometer probes during transition periods can be avoided by sensible probe placement and mounting, as well as by an ideal configuration of the probe's automatic cleaning system.

Fast run-off from the installation can be ensured by tilting the probe in combination with high-frequency and high-pressure automatic cleaning. Additional panels on a mounting system can circumvent run-off from the installation over the measurement windows of spectrometer probes and thereby prevent plaque formation induced by held-back debris.

Patterns during transition periods can serve as indicators for the quality of probe placement, installation and configuration. In case of optimal placement, installation and configuration, the behavioural characteristics are very pronounced over a short window of time (Run-Off pattern) or do not occur at all (two-level-shift pattern and fouling due to prolonged transition periods).

3.3 Dry state

The state of *dry* operation describes periods of time during which the spectrometer probe *falls dry*, meaning possible run-off from the probe or its mounts has passed the measurement window and at least the majority of the probe corpus is relatively dry; while assuming no clogging has occurred. Additionally, a sufficient distance to any neighbouring fluid's surface is required. Comparable to the patterns during submersion and transition periods, those occurring during dry periods were relatively consistent for all laboratory experiments and field trials.

Assuming all aspects to ensure optimal probe operation during submersion and transition periods have been considered and implemented, negative behaviour during dry operation has already been reduced to some extent and the remaining patterns in the time series during dry periods, all indicating probe fouling, depend heavily on the configuration of the probe. This assumption suggests that the remaining aspects of probe fouling are inherent to the optical measuring principle applied by spectrometer probes. A theory, underlined by the fact, that the following effects were observed in similar form but to different degrees on all test sites in the field, as well as during all the laboratory experiments.

Due to the similarity of these characteristics, the behaviour of spectrometer probes during phases of dry operation, could serve as a reliable indicator for the quality of the data generated by these probes in general. Consequences of mismanagement (e.g. insufficient manual cleaning) or sub-optimal configuration of the system (e.g. cleaning pikes in the time series of vertically installed spectrometer probes) become apparent once a probe falls dry. The majority of negative behaviour, which is visible in the time series during dry operation, translates to a distortion of the measurement results during submersion in one way or another.

Since highly accurate data is a key requirement for the application of spectrometer probes in the control of processes of treatment plants or pollution based discharge control of storage facilities for combined wastewater, like the CST, early detection of fouling during dry periods is a perquisite to conduct timely probe maintenance between storage events or overflow periods. Therefore, pattern identification in the time series of spectrometer probes during dry phases offers an opportunity for operational optimisation and site-specific maintenance planning. This is of particular interest, as probes installed in-line, can only be reached to perform modifications or cleaning, between submersion events. Although, a possible shutdown of the system during dry periods would e.g. reduce costs for electricity or reduce the amount of recorded data and would extend lifetime of the used xenon flash in the spectrometers, the additional output in metadata during dry operation and the possible implications of this information for maintenance planning, warrant permanent probe operation in systems with temporary submersion.

3.3.1 Run-Off pattern during dry periods

This pattern is induced by lime scale on the measurement windows of spectrometer probes, when automatically cleaned with tap water and very likely amplified by vertical probe installation. In its periodic characteristic, this effect is similar to sedimentation processes between automatic probe cleaning flushes during submersion periods as defined in section 3.1.1. The reason for the characteristic *shark fin* pattern of Figure 3-15 [1] is calcium carbonate residue in the run-off from the probe after an automatic cleaning flush in combination with minimal leaking from the tap water lining to the probe.

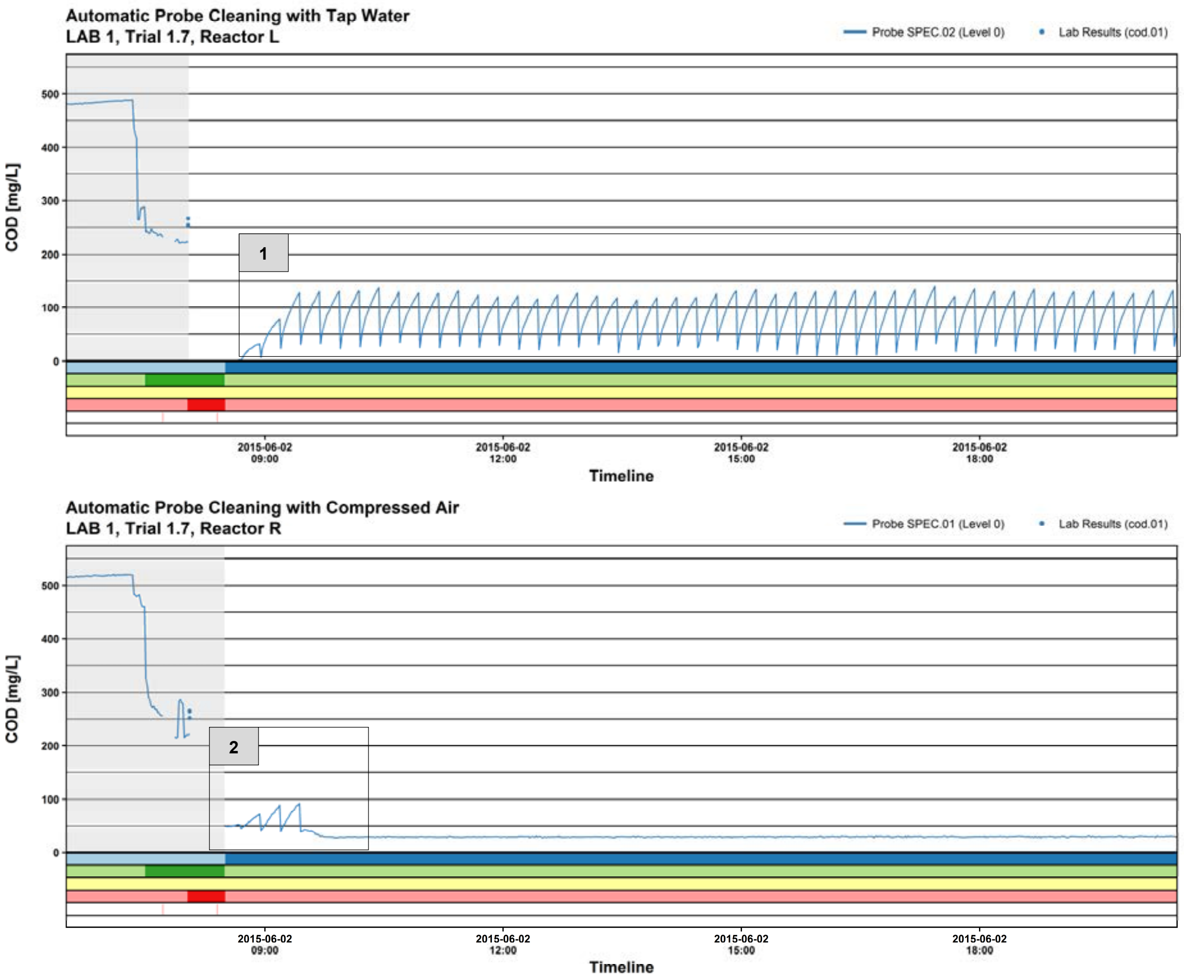

Figure 3-15: Run-Off pattern when using tap water (top) and Run-Off pattern when using compressed air (bottom) for automatic probe cleaning during Trial 1.7 of LAB 1

During Trial 1.7 the time window between tap water flushes was not long enough for the residue to settle permanently. Thus, no durable or permanent plaque was formed, resulting in the regular, continuous pattern depicted in Figure 3-15 [1]. Nonetheless, it is expected that long-term automatic cleaning with tap water of a certain hardness would induce plaque and thereby result in probe fouling. This theory could be verified by the application of distilled water as a cleaning agent for automatic probe cleaning.

In contrast to Figure 3-15 [1], automatic probe cleaning with compressed air under otherwise identical conditions resulted in a damped form of the shark fin pattern like the R*un-Off* characteristic described in section 3.2.1 and highlighted in Figure 3-15 [2]. Contrary to the behaviour in Figure 3-15 [1] this pattern transitions into a stable concentration level.

While automatic probe cleaning with tap water was not tested in the laboratory during submersion periods to avoid sample dilution in the reactors, it seems to offer some advantages over compressed air, in particular if mixed with cleaning agents, in the field. If there is a possibility to avoid frost damage to the cleaning lines to the probes, the use of (tap) water as vehicle for cleaning agents, might be a viable alternative to compressed air for the automatic cleaning of spectrometer probes in systems with operating conditions comparable to the CST.

3.3.2 Shift pattern during dry periods

Throughout the laboratory and field trials for this thesis, a variety of *shift* patterns in the time series of spectrometer probes, characterised by a more or less instant increase or decrease in resulting parameter concentrations, have been observed. These shift patterns can occur in the form of a decrease in concentration, considered as *negative* shift and in the form of an increase in concentration, considered as *positive* shift.

A negative shift in the data occurs, when the probe is cleaned, either manually or by Wash-Off after submersions events, as described in chapter 3.1.2. Positive shifts in the time series can sometimes occur after submersion events, indicating clogging or a form of probe fouling. Incorrect maintenance or insufficient cleaning of spectrometer probes can result in positive shifts as well.

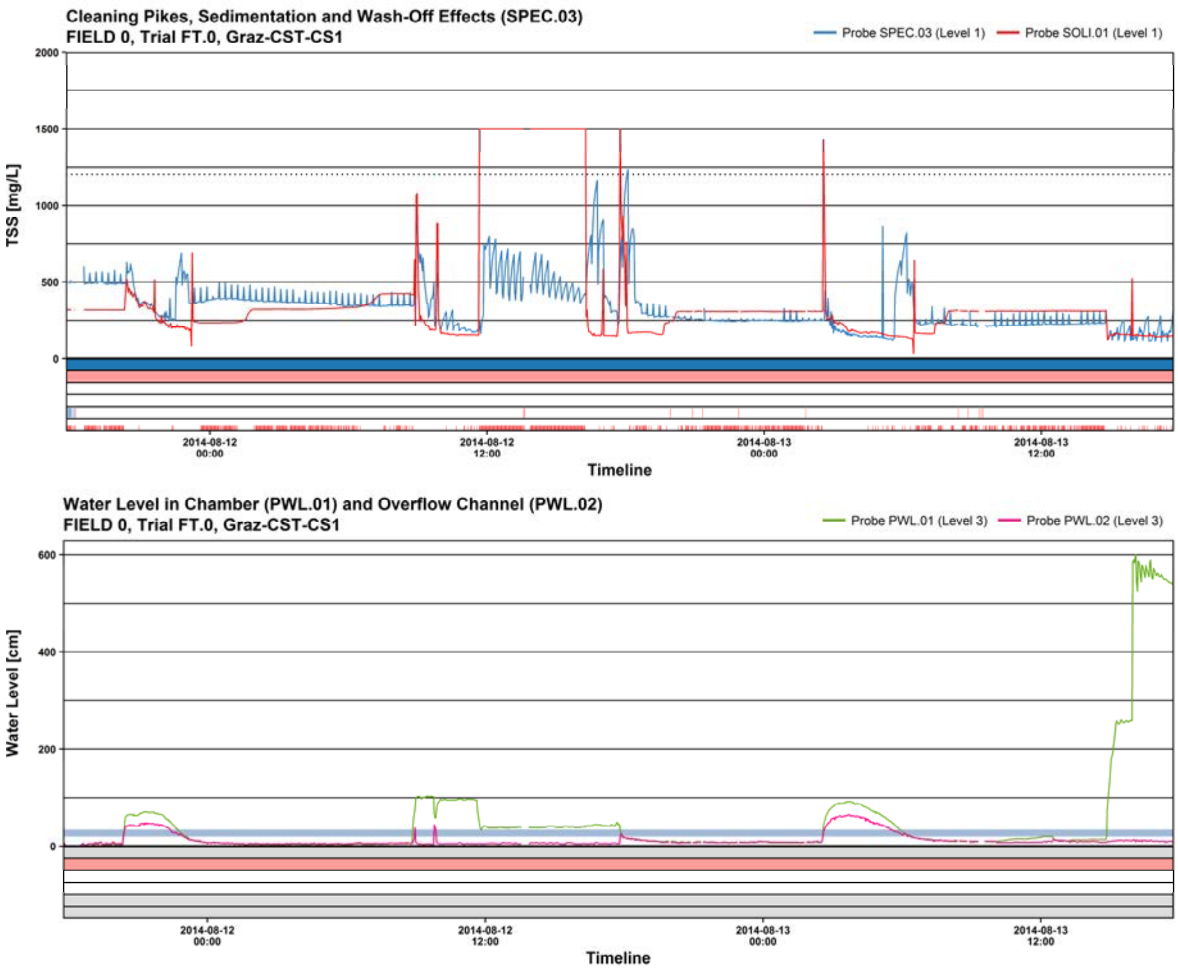

Figure 3-16: Series of positive and negative shift patterns between submersion periods during Trial FT.0 of FIELD 0

Figure 3-16 depicts a series of positive and negative shifts in the TSS concentrations of the probes SPEC.03 and SOLI.01, pointing to probe fouling in the form of plaque formation and plaque removal by Wash-Off respectively. No manual probe cleaning was performed during the depicted period.

Symptomatic for shift patterns is, that they do not develop over time like drift patterns. Immediately after the end of a submersion period or at the latest after the run-off from the installation over the probe's measurement window has ceased (end of the transition period), a shift in the base line of a parameter occurred. Figure 3-17 [1] is an example for negative shift as a direct consequence of the submersion event in Figure 3-17 [2]. The TSS concentration of the spectrometer probe in the upper chart drops approximately 300 mg/L as the water level drops below the probe's sensor. While such shift patterns are induced by submersion events, the first time they can be detected is during the following dry period after the end of the transition period. This fact constituted the assignment of shift patterns like the one in Figure 3-17 to the dry state for spectrometer probe operation.

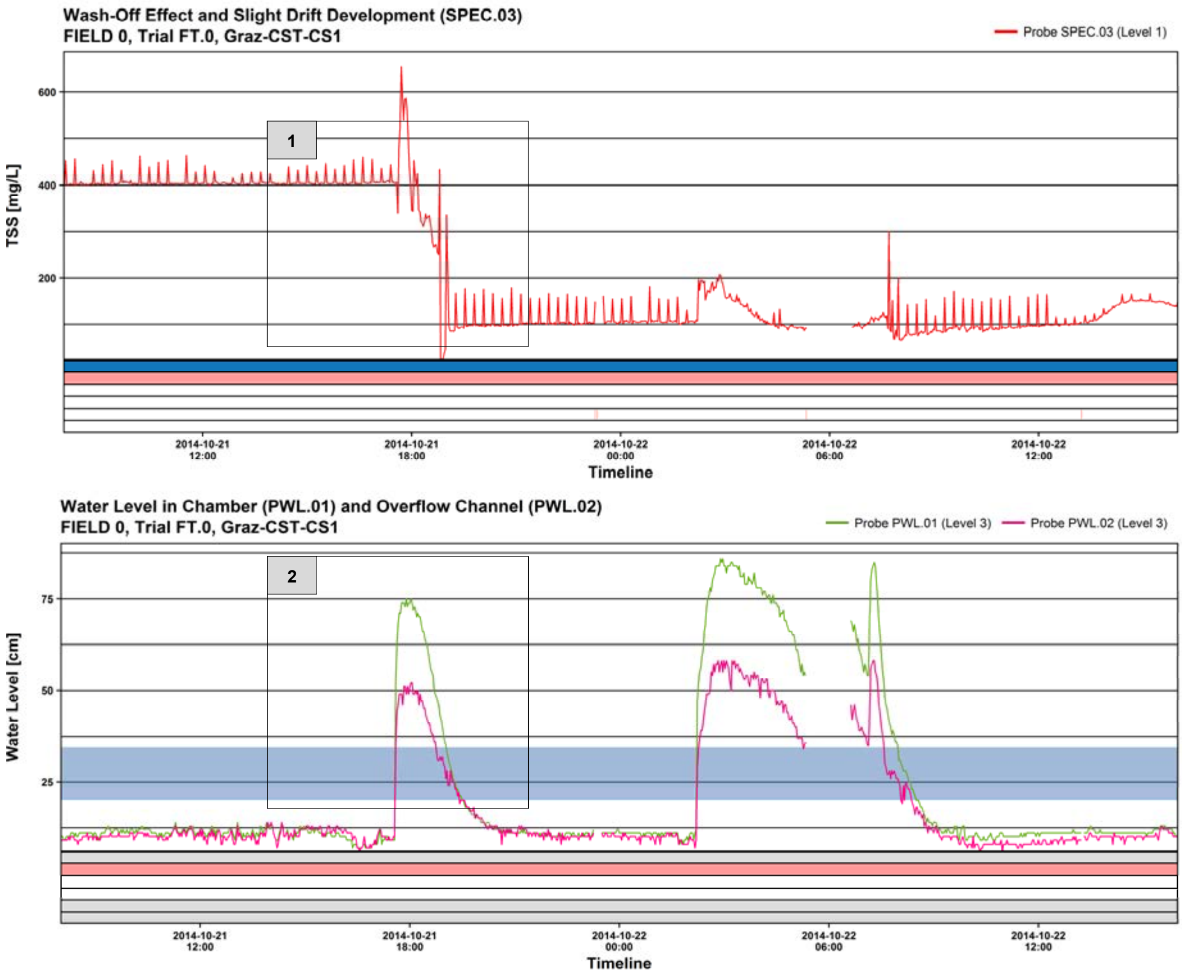

Figure 3-17: Negative shift (Wash-Off phenomenon) during Trial FT.0 of FIELD 0

Figure 3-18 [2] shows negative shift in the COD concentrations of a spectrometer probe as a result of manual probe cleaning after a submersion event. In this case the dynamics of the preceding submersion event were not enough to reduce probe fouling (Figure 3-18 [1]). Automatic probe cleaning was working properly, as indicated by the Run-Off pattern in Figure 3-18 [3], which was generated by the run-off of the cleaning agents applied during manual probe cleaning (hydrochloric acid). After the manual cleaning process, the base line of the probe starts to *drift* slightly, meaning a continuous increase in concentration without exposure to a submersion medium (Figure 3-18 [4]).

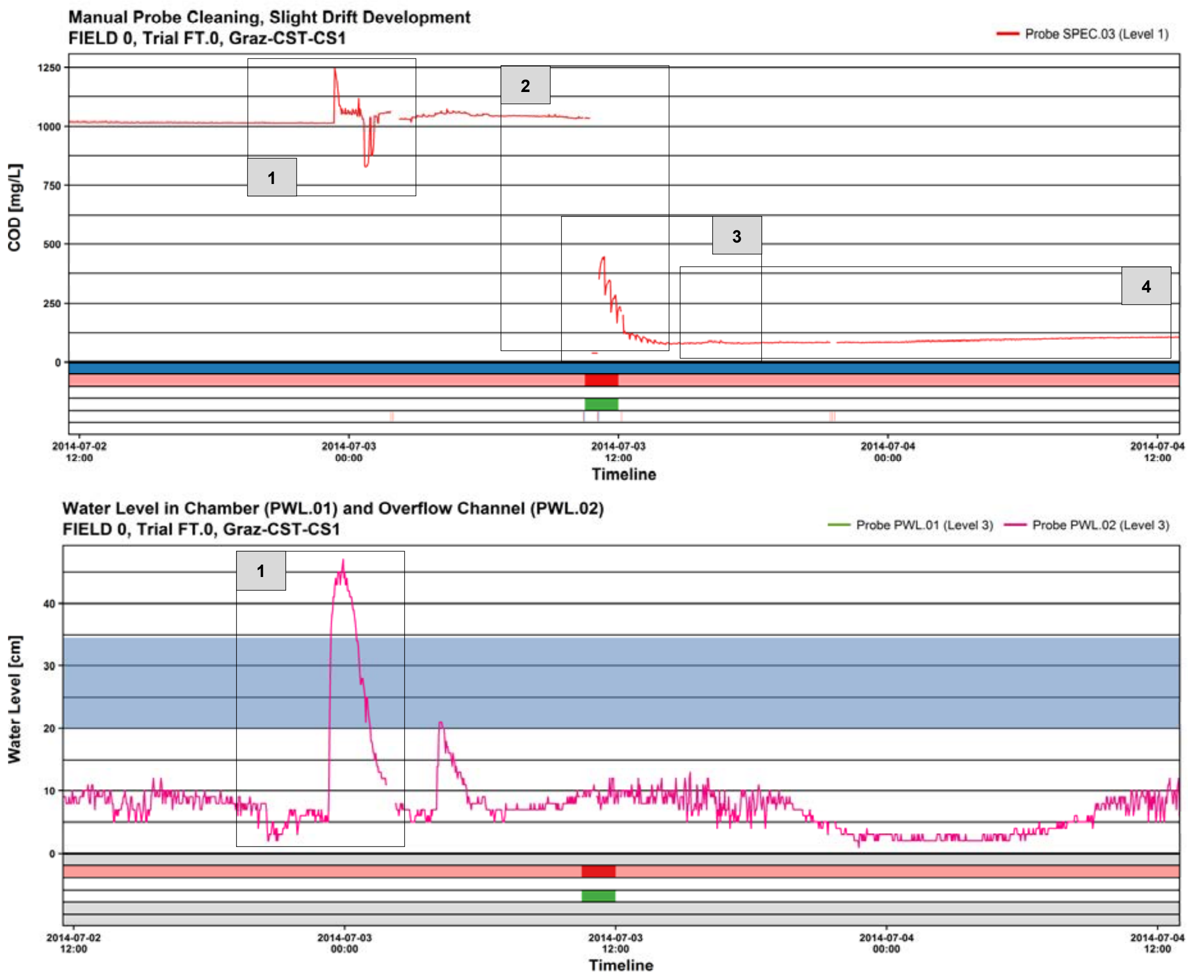

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Figure 3-18: Negative shift as a consequence of manual probe cleaning during Trial FT.0 of FIELD 0

As only minor drift development was observed with spectrometer probes during laboratory and field trials, shift development might be the best indicator to assess the degree of fouling for this type of in-line equipment. Shift behaviour during dry periods could be applied as indicator for the need for maintenance of spectrometer probes exposed to the alternating conditions of the CST.

A comparison of Figure 3-19 and Figure 3-20 leads to the assumption that a positive shift in the concentration baselines of spectrometer probes, induced by submersion events (grey background), which indicates probe fouling, can be reduced or at least avoided by an ideal automatic probe cleaning configuration. In the two figures, the increase in concentration for sum parameter TSS before (odd numbers [1] and [3]) and after (even numbers [2] and [4]) the submersion period, seems to be less significant when automatic probe cleaning is applied, ideally at a high frequency. As a consequnece of the high automatic probe cleaning frequency in Figure 3-20, marked by the ticks at the top of the two time series charts in this figure, sedimetation during submersion is reduced and the blow-out of the run-off is accelerated.

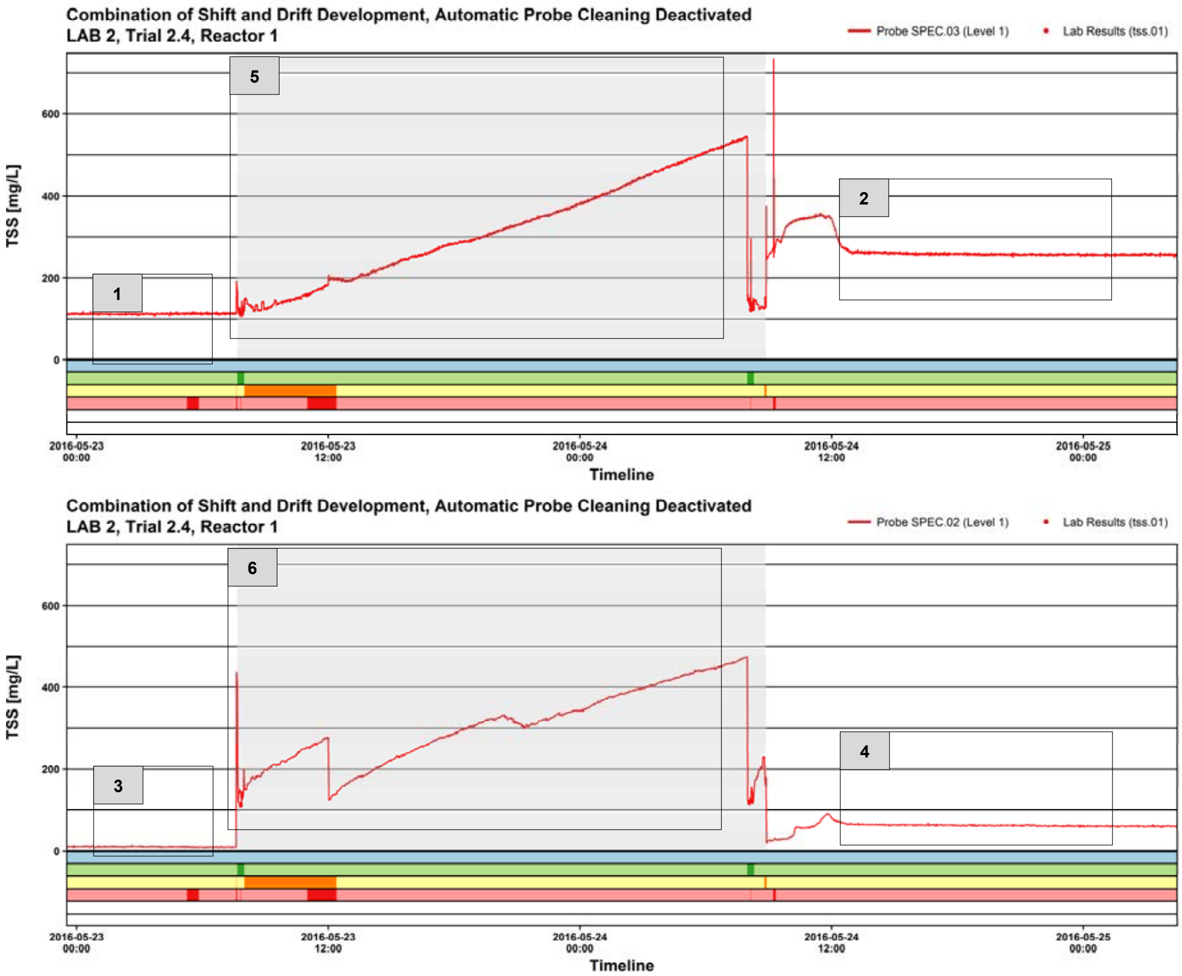

Figure 3-19: Shift in the TSS baseline after a submersion event without automatic probe cleaning during Trial 2.4 of LAB 2

The peaks in the time series during the submersion period in Figure 3-19 [6] were induced by manuipulation of the reactor which was necessary after a leak in the bottom plate occurred. After fixing the leak, an additional CWS sample volume of approximately 10 litres had to be added from the top of the reactor to compensate for the loss. The addition of this CWS sample caused the highlighted pattern as it interrupted the expected contiuous sedimenent accumulation in the measurement window of the spectrometer probe like is was observed in Figure 3-19 [5].

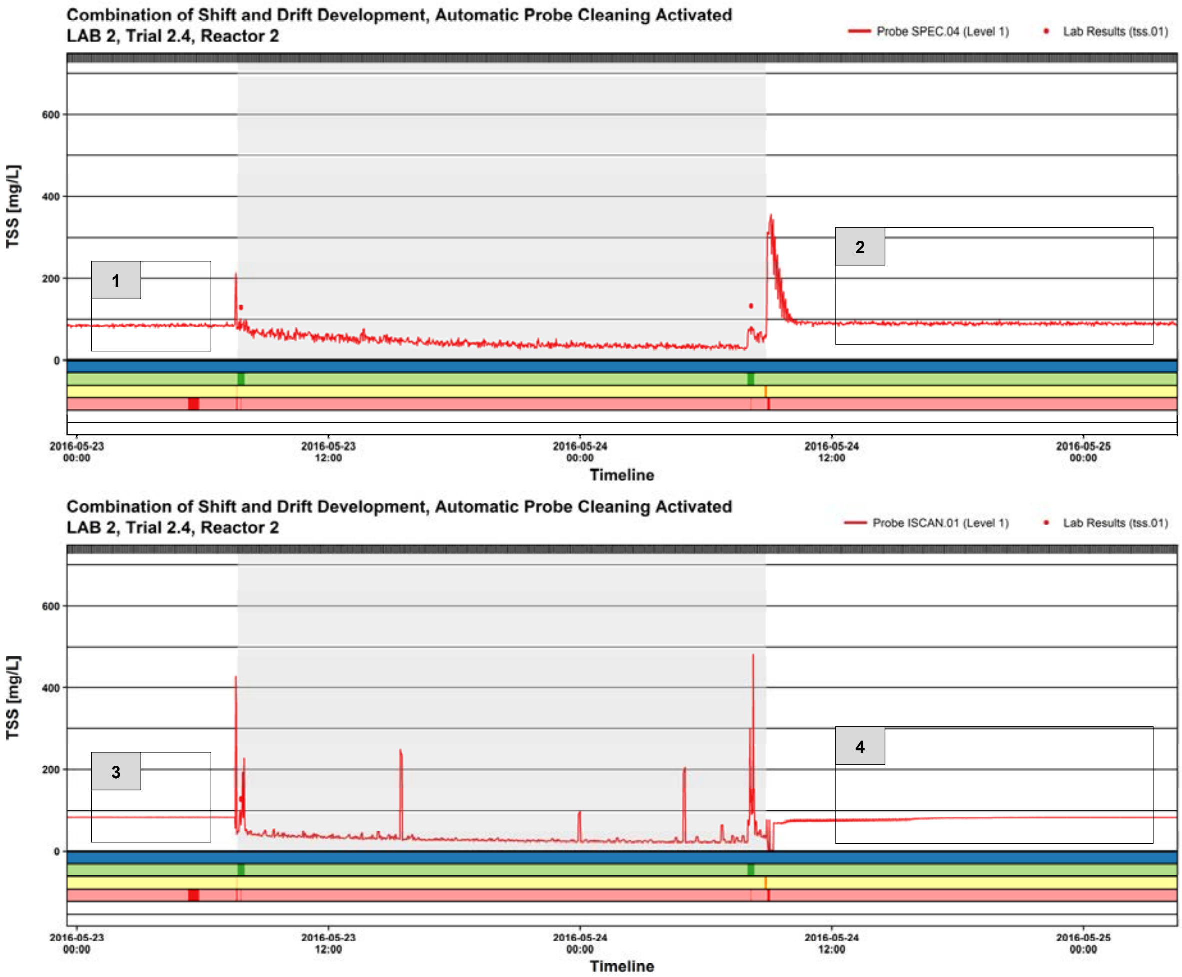

Figure 3-20: Shift in the TSS baseline after a submersion event with activated automatic probe cleaning during Trial 2.4 of LAB 2

3.3.3 Drift pattern during dry periods

Unlike the shift patterns in the previous section, *drift* during dry periods develops over time as a continuous increase in the concentration of a parameter without any obvious and immediate exposure to a submersion medium.

As a likely consequence of the low pollutant concentrations in the CWW on site and the CWS intended to emulate the medium in the CST, which was used for the laboratory trials, drift during dry periods did not present itself as a considerable problem, as long as the probes are maintained regularly. While minimal drift was observed between storage events in the CST as a consequence of residue accumulation on sensors during probe submersion, it is mainly of concern as an indicator for the quality of manual probe cleaning as shown in Figure 3-21, where drift ensues without probe cleaning in Figure 3-21 [1] as opposed to the stable base line after manual probe cleaning in Figure 3-21 [2]. The peak in the drift in Figure 3-21 [1] is attributed to the degradation of volatile residue while the probe warms after submersion, before a more or less stable, but elevated, base line forms.

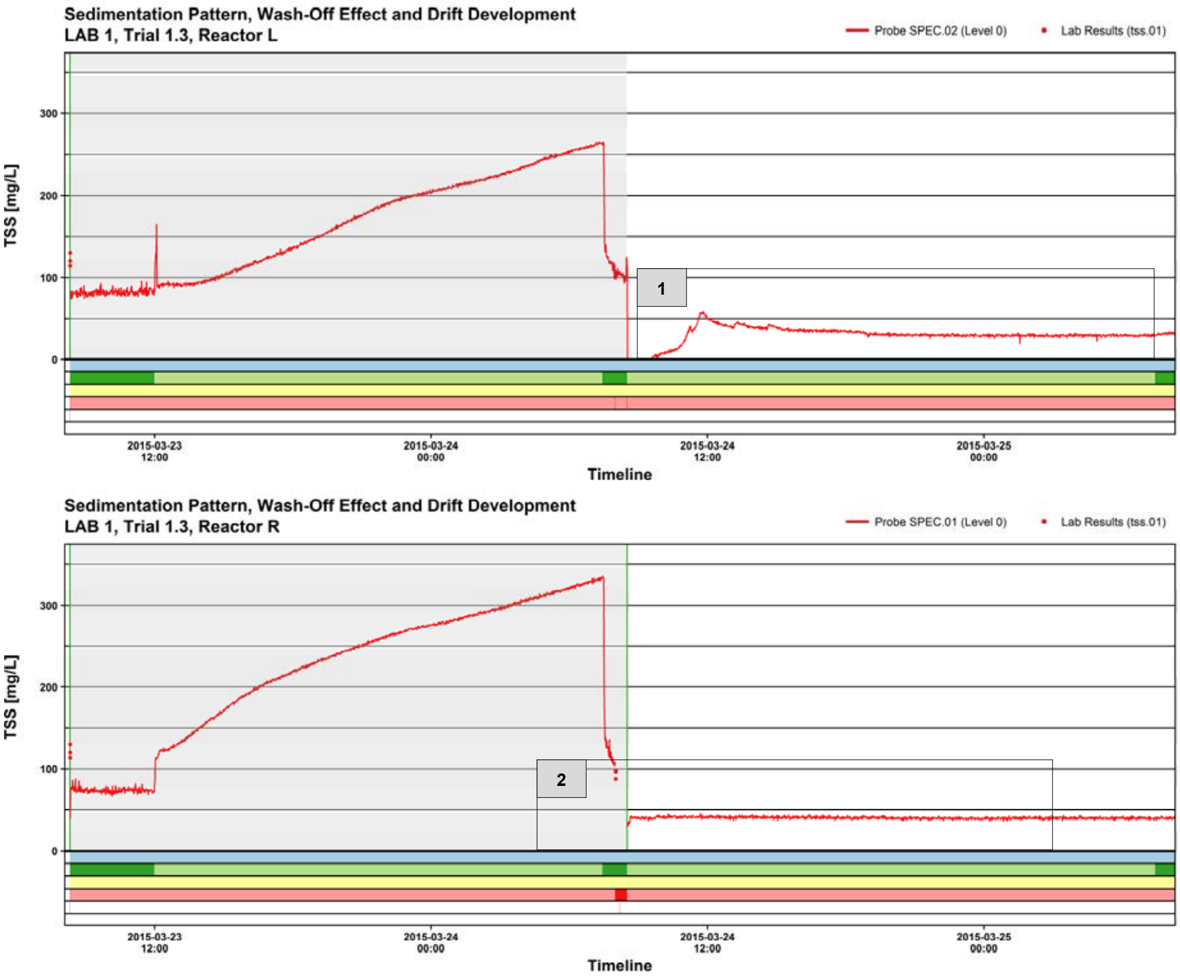

Figure 3-21: Sedimentation in the measurement window and drift development without probe cleaning during Trial 1.3 of LAB 1

Data from field testing and laboratory experiments suggests the formation of a site-specific *secondary base line* for most parameters, likely after a short drift period.

The term *secondary base line* is aimed at describing stable, but elevated concentrations levels for a parameter during dry periods (Figure 3-20 [1]), which lie significantly above the concentration level in the cleanest state of a spectrometer probe after thorough manual cleaning (Figure 3-20 [2]).

On site, secondary base lines formed on probes after manual cleaning during FIELD 0 and FIELD 1. Examples of this behaviour are given in Figure 3-22 [2] and more distinctly in Figure 3-22 [3]. Compared to the negative shift in the data as a result of the manual probe clearing in in Figure 3-22 [1] the drift development in Figure 3-22 [2] is less pronounced. It is likely caused by the accumulation of particles from the ambient air (accelerated by the constant draft in combined sewers) on the wet measurement window, this type of fouling does not lead to permanent plaque formation, as the particles can usually be removed manually with dry paper towels and are washed off instantly once the spectrometer probe is submerged again.

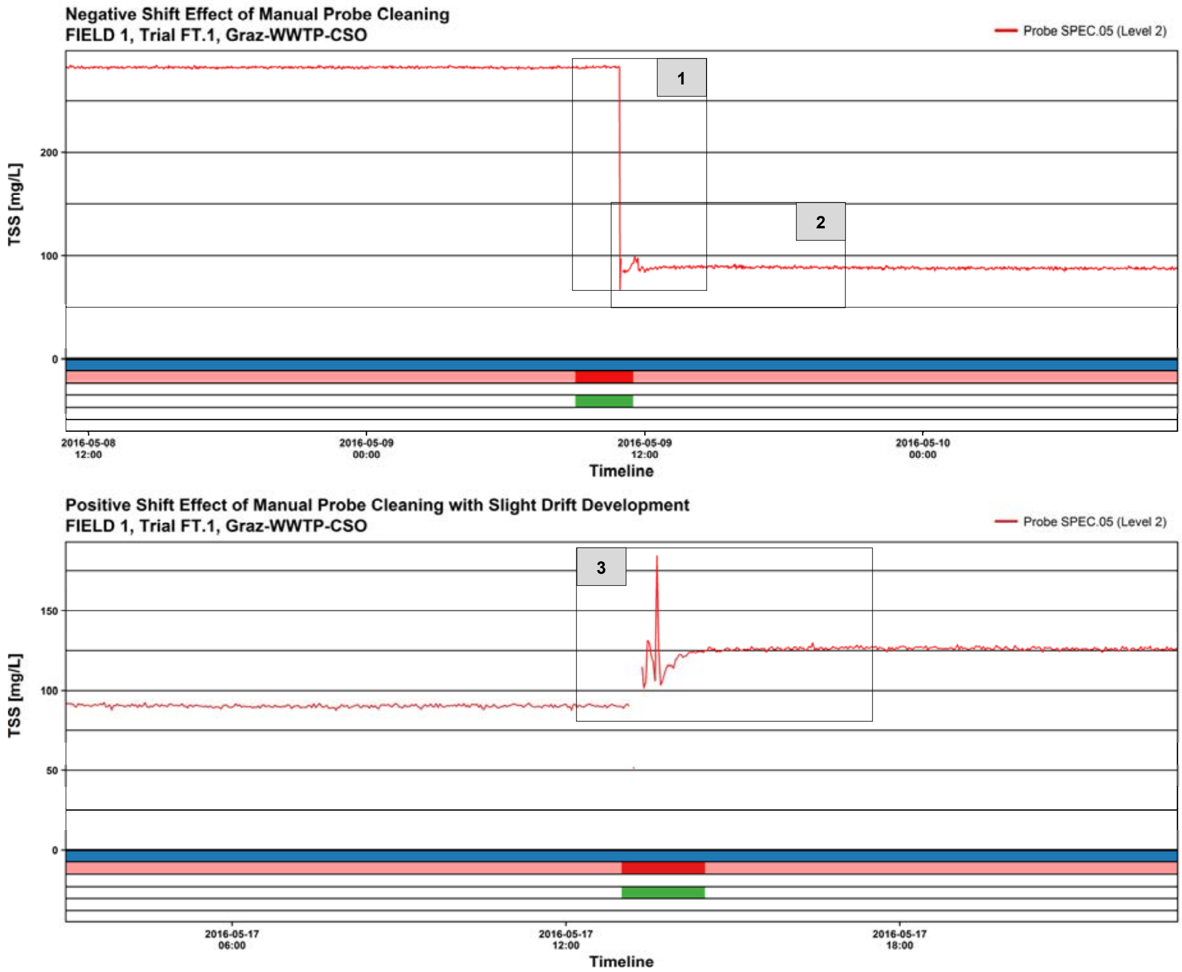

Figure 3-22: Drift development after manual probe cleaning (secondary base line) during and Trial FT.1 of FIELD 1

In the field, this secondary base line and its ratio to the base line of the spectrometer probe immediately after manual cleaning has proven itself to be a reliable indicator for possible probe damage due to humidity in the casing as a result of defects of the hull or in the seal around the lead-in of the power cord. Once the hull is perforated, the permeating humidity cumulates in the measurement windows of vertically installed spectrometers. This accumulation leads to an unreasonably high base line and remains at that level even after intensive cleaning of the measurement windows.

Drift development during dry periods was not a point of concern in the combined wastewater and combined wastewater substitute used for this thesis. Such patterns only developed slowly during dry periods and the increase in concentration for most sum parameters was rather insignificant compared to the observed shift patterns, in particular for TSS and COD. For those parameters drift patterns were difficult to identify or did not occur at all.

Figure 3-23 [1] shows the effect of manual probe cleaning on the COD concentration, in the form of two shifts, before the concentration remains at an elevated, but rather stable level. No significant drift can be observed. The elevated concentration level goes beyond a secondary base line and indicates insufficient cleaning and thus, plaque in the measurement window. Especially, as it remains at that level for two submersion events. In Figure 3-23 [2], a second manual cleaning process results in removal of the plaque, indicated by a negative shift on the level of the base line expected for a clean probe, before formation of the site-specific secondary base line after another submersion event.

Sum parameters other than COD and TSS, for instance CODf, exhibit a more distinct drift behaviour, as shown in the continuous convergence towards a concentration level after manual cleaning in Figure 3-23 [3]. Comparable to parameter COD, this concentration level for CODf exceeds the level expected for a secondary base line and corroborates the idea of fouling due to insufficient probe cleaning. Behaviour during and after the second cleaning process in Figure 3-23 [4] is identical to Figure 3-23 [3].

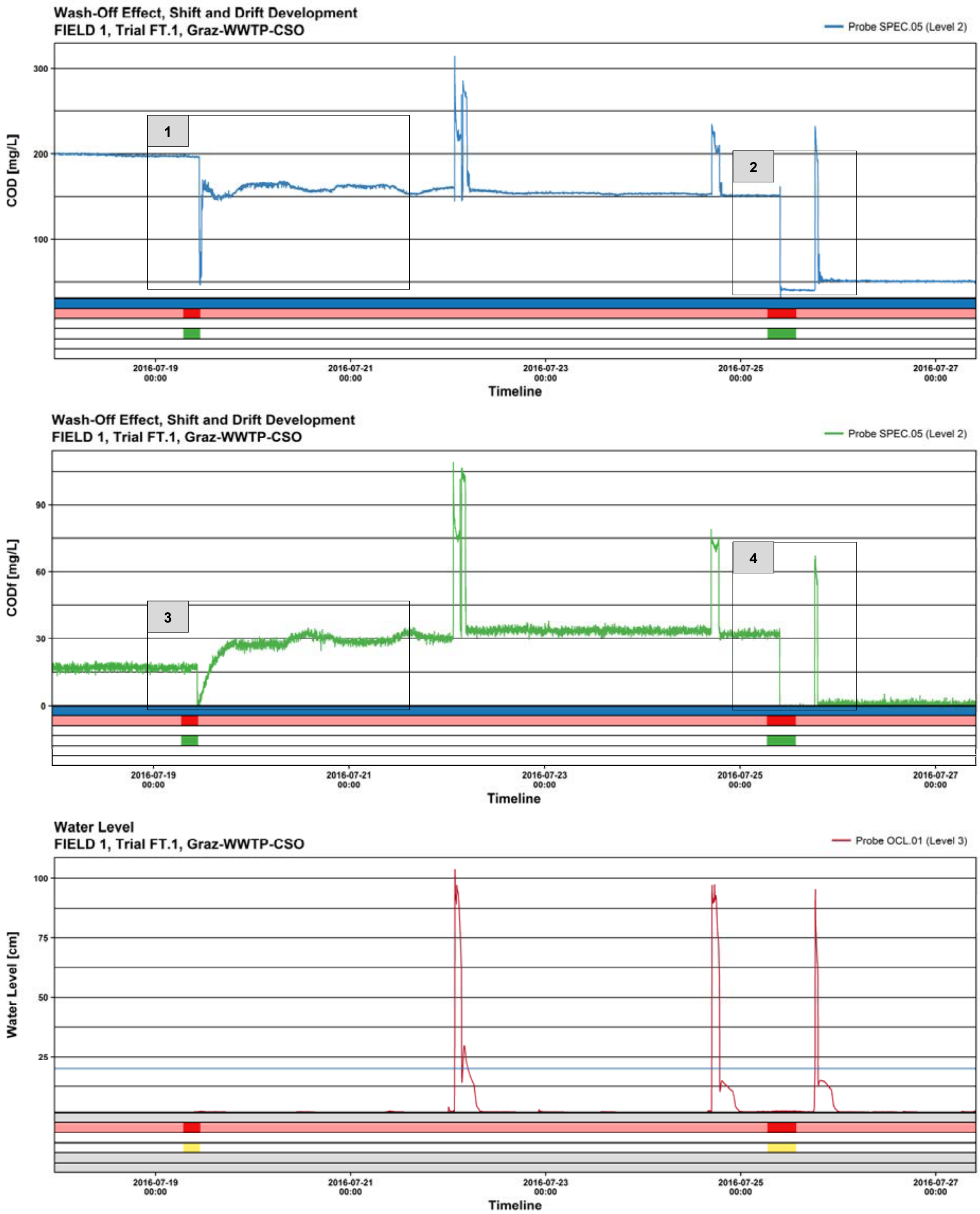

Figure 3-23: Combination of drift and shift development during Trial FT.1 of FIELD 1

3.3.4 Pikes in the time series during dry periods

Repetitive pikes linked to automatic probe cleaning flushes of the spectrometer probe were identified during field testing programme FIELD 0. Each concentration pike in the time series of probe SPEC.03 as marked in Figure 3-24 [1] is linked to a compressed air flush. While it does not seem to have an immediate effect (positive or negative) on the overall behaviour of the probe in the most general sense, it acts as a clear indicator for the insufficient performance of the compressor used for automatic probe cleaning and a sub-optimal equipment configuration. Since this effect was only observed for the vertically installed spectrometer probe but not for probe SOLI.01, the measuring path of which is oriented horizontally, it seems to be linked to the inclination of the probe. Even though the pikes do not occur visibly in the time series during the periods of submersion periods in Figure 3-24 [2] and Figure 3-24 [3], they point to a mistake in the configuration of the equipment.

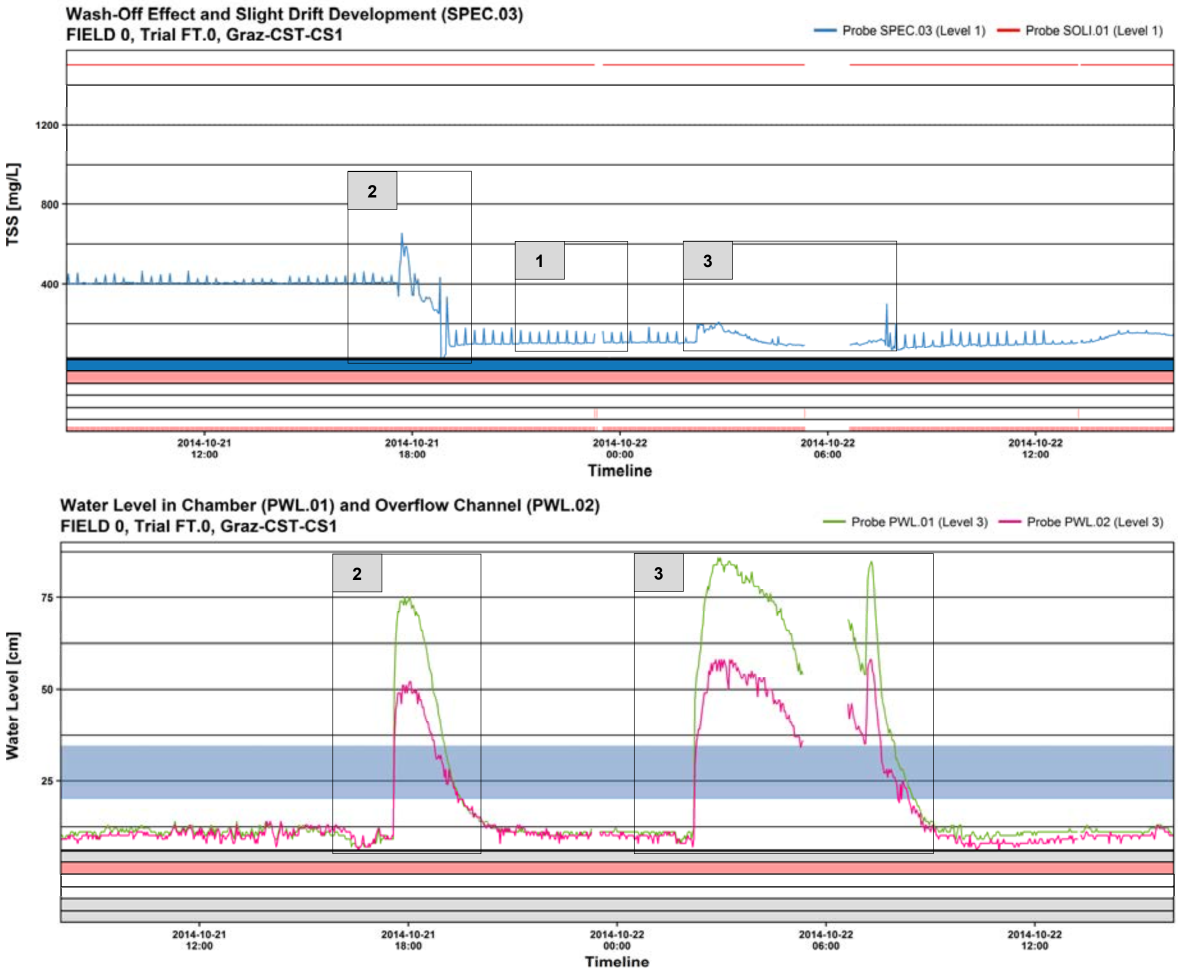

Figure 3-24: Automatic probe cleaning pikes during Trial FT.0 of FIELD 0

The control unit of Graz-CST-CS1 operates a large number of probes at a 120 second measuring interval, which represents the smallest stable interval given by the equipment configuration at the station. As a consequence, a minimal time gap of a few seconds between automatic probe cleaning flushes and the triggering of subsequent measurements was available to - at least theoretically - keep within the narrow limits of the measuring interval. Due to limited access to the installation, the exact value of this time gap was not known. When additionally taking into account the length of more than ten metres of the compressed air lines between the magnetic valve in the control room at CS 1 and the probes in the chamber below, it is reasonable to assume that the cleaning pikes are a result of measurements starting in the trail of automatic probe cleaning flushes. Since no check valves were installed at Graz-CST-CS1 during FIELD 0, the compressed air might also be laced with dirt and capillary water from submersion periods, enhancing the concentration pikes during dry periods.

During the submersion periods, this effect might not be visible, due to a changed pressure ratio between the filled chamber at CS 1 and the compressed air flushes from the compressor. Nonetheless, measurements of the spectrometer probe after automatic cleaning flushes are likely deprecated during submersion periods as well, due to the interference of air bubbles in the measurement window.

3.3.5 Conclusions for operational optimisation during dry periods

Though dry periods themselves are not of interest for the operation of spectrometer probes in sewers and storage facilities with intermittent probe submersion, they offer significant insight in the reliability of the monitoring equipment and are thereby an important quality indicator for the generated data.

Patterns like the cleaning pikes described in the previous section, provide information on the status of the equipment configuration of a monitoring station.

Fouling during dry periods can serve as an indicator for necessary changes to the mounting system and the need for on-site maintenance. In general, dry periods are of particular significance for maintenance planning, since in-line equipment can only be accessed expediently and safely between submersion events.

Drift development, which was widely considered (Gruber et al., 2015) as the dominant and most problematic form of fouling for spectrometer probes during dry periods when exposed to the conditions in the CST, was not nearly as significant as expected.

3.4 Conclusions for operational optimisation

3.4.1 Measures to optimise probe placement, installation and configuration

Based on the findings from laboratory experiments and field trials, characteristic patterns in the time series of spectrometer probes in systems with alternating submersion conditions were identified and linked to their respective sources. By analysing patterns for submersion, transition and dry periods separately before combining the findings, considering the interdependencies between the operational states, a systematic approach for optimising the operation of spectrometer probes in systems like the CST in Graz, Austria was developed.

At the foundation of any optimisation process in this context lies the placement of the in-line monitoring equipment and the use of a suitable mounting system. Placement and mounting system should be adjusted iteratively. The goal is to avoid interference from the monitoring equipment or the operational environment on the generated data. By, for example, ensuring a sufficient flow in the measuring medium or a suitable probe inclination, a majority of negative behavioural characteristics can be avoided. The mounting system should prevent clogging of the equipment, while facilitating fast run-off over the probes in cases where it cannot be avoided entirely.

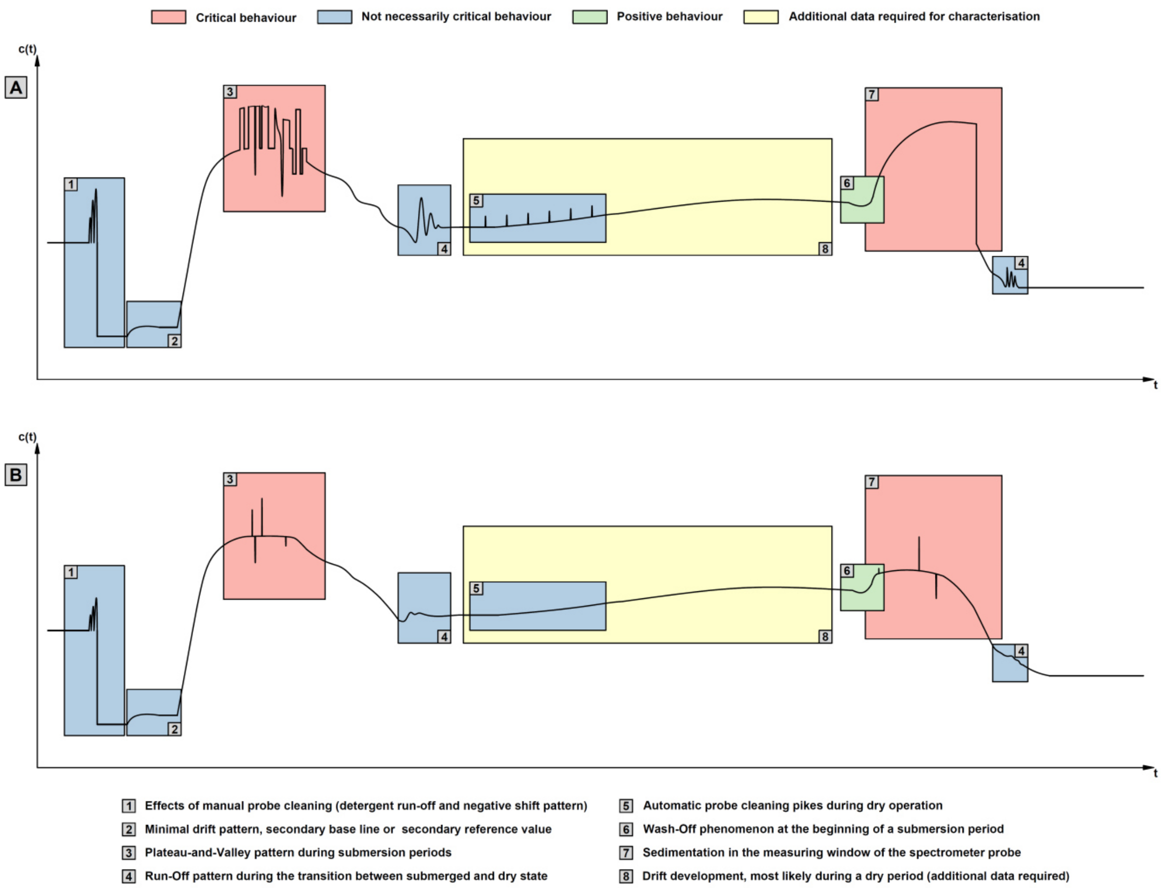

Figure 3-25: Reduction of negative effects in the time series of spectrometer probes by an adaptation of mounting system and equipment configuration

Once placement and mounting are optimised, the next step is to adapt the configuration of the equipment, especially the medium, lining and pressure for automatic probe cleaning to foster the generation of a high-quality and high-resolution time series during submersion periods, while stimulating the removal of residue during transition periods and avoiding probe fouling during dry periods.

Figure 3-25 [A] shows an exemplary worst-case time series for the current installation in the CST, containing multiple patterns which indicate a corruption of the monitoring results, as discussed in the previous sections of this chapter. After implementing the measures proposed above, the pre-validated time series in Figure 3-25 [B] is generated and the focus can shift towards finding an optimal relationship between high-quality data and minimal maintenance efforts.

Spectrometer probes, in particular the *spectro::lyser* probes used for this thesis seem to work best when the operational environment shows sufficient flow dynamics during periods of submersion and the automatic probe cleaning feature is set to a high frequency with the highest possible pressure. If this is the case, sediment accumulation in the measurement window can be avoided entirely. If sedimentation processes in a submersion medium are an issue or of interest, spectrometer probes should be installed horizontally to avoid inaccurate results due to sediment accumulation in measurement windows.

During submersion periods, a sufficient inclination of spectrometer probes is required to avoid the entrapment of air bubbles in measurement windows, especially in environments with limited or no flow nearby the sensor. In this case, laboratory experiments showed that the use of check valves directly at the interface between compressed air lines and the fittings behind the borings on the probes avoids the intake of combined wastewater and dirt in the supply lines, while simultaneously reducing the Plateau-and-Valley pattern in the time series.

The application of check valves and the prevented intake of waste and fluids in the compressed air lines might also reduce the extent of the cleaning pikes observed in the data from trial programme FIELD 0. The length of the lines supplying the cleaning agent between the magnetic valve triggering the cleaning flushes in the control room and the probe(s) in the sewer, need to be taken into account when defining the automatic probe cleaning settings and the overall configuration of the equipment (e.g. the measuring interval or the number of probes connected to a single control unit). This measure is aimed at avoiding the start of measurements following automatic cleaning flushes, before the compressed air or tap water of the flush has passed the measurement window of connected probes. Furthermore, the coordination of the measuring interval and the automatic probe cleaning settings avoids the generation of identical subsequent measurements as a results of an overburdened control unit.

Regardless of the application of a flexible or an inflexible installation design for a water quality monitoring installation, run-off from the probe mount across the measurement window of spectrometer probes should be kept to a minimum or avoided entirely. This can be achieved by a proper design of the mounting system and the use of feasible covers. If sufficient pressure for automatic probe cleaning in combination with a high cleaning frequency is provided, unavoidable run-off can be removed (almost) instantly at the beginning of the transition period after submersion events, no matter what cleaning medium is used. This run-off process can be accelerated by installing the probe with a sufficient inclination.

Given the fact that only limited modifications to the existing water quality monitoring installation in the CST are possible, the implementation of the changes proposed throughout this chapter can be condensed into five bullet points. This set of measures is intended to combine the conclusions from FIELD 0, LAB 1, LAB 2 and FIELD 1 for operational optimisation of temporarily dry falling spectrometer probes in combined wastewater. All measures are intended to keep within the requirements proposed in the probe manuals (s::can Messtechnik GmbH, 2007, 2011):

- All water quality probes should be mounted at the same level and the inclinations of optical probes should be increased significantly. The extent of the increase needs to be determined on site and tested individually for every probe.
- The sheet metal cover should be perforated and modified to avoid run-off from the installation over the spectrometer probe and to offer room for adapted probe inclinations.
- The configuration of the equipment (e.g. the measuring interval and the automatic probe cleaning settings) should be revised and altered to a point where stable operation is ensured.
- Check valves should be installed for all probes cleaned with compressed air.
- The use of a second magnetic valve for compressed air cleaning and the necessary adaptation of the equipment configuration should be tested.

Laboratory and field data corroborated the assumptions made for optimal operation of spectrometer probes in systems with alternating operating conditions of chapter 1.2. An approach for reducing maintenance efforts, once these measures are implemented on site, is presented in section 3.4.2.

Although it was no viable option for this thesis, it should be mentioned that a different probe mount and adjustments to the placement of the existing installation could be considered as options to increase the performance of station Graz-CST-CS1 even further. Additionally, there might be suitable alternative concepts and monitoring sites in the context of the CST and WWTP Graz, where the operation of a monitoring station fulfilling the purpose of Graz-CST-CS1 is possible, while facilitating more efficient probe operation and management.

3.4.2 An algorithm for the implementation of condition-based maintenance

Once the placement and configuration of the in-line probes, as well as the design of their mounting system is optimised as described in the previous section, the focus can be shifted towards reducing the efforts for on-site probe maintenance.

During the initial field testing programme (FIELD 0) for this work, maintenance of the equipment installed in the CST was carried out very irregularly since the CST was not in full operation. To conduct on-site maintenance, at least three trained staff members of the Institute of Urban Water Management and Landscape Water Engineering of Graz University of Technology were required to keep within safety regulations and provide efficient cleaning of the installed probes. Cleaning took place after events, regardless of the behaviour of the in-line probes, as depicted for a secondary probe in Figure 3-26 [A] and for a primary probe in Figure 3-26 [B].

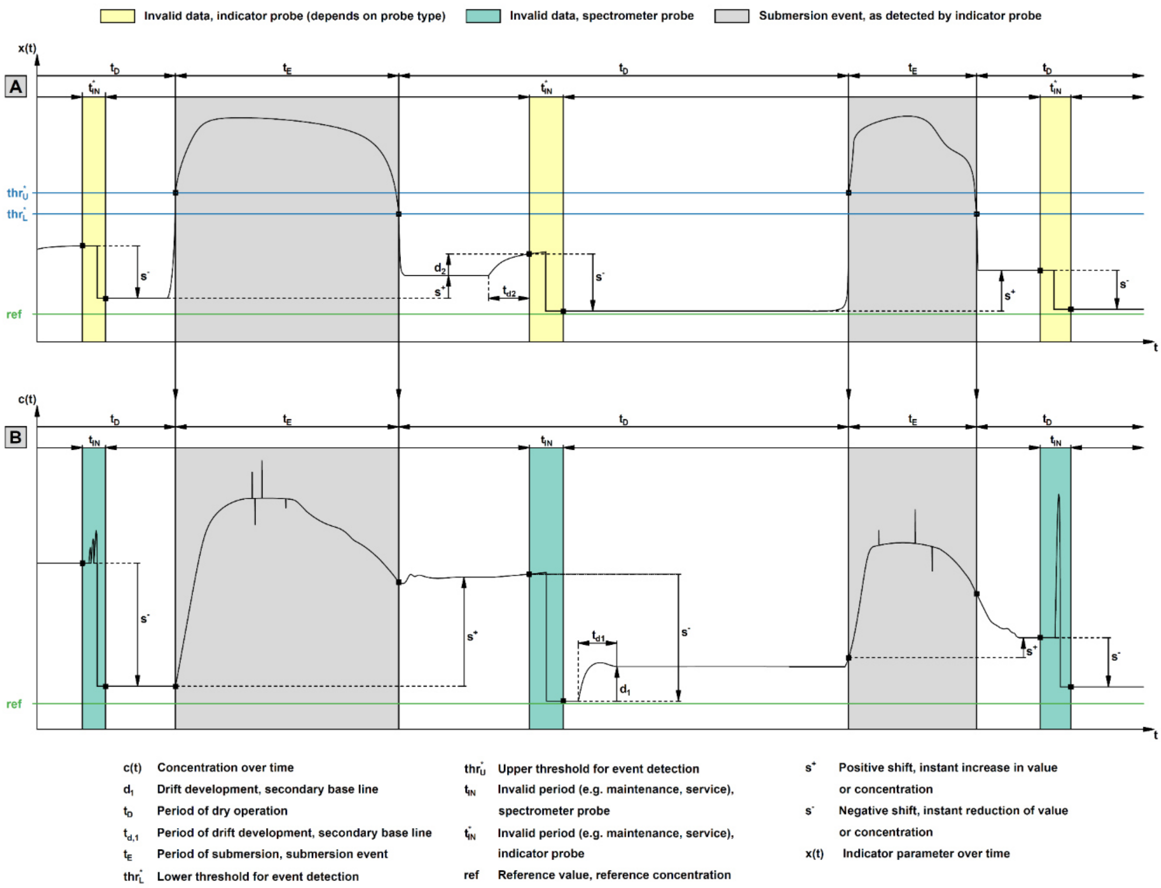

Figure 3-26: Probe maintenance based on a fixed schedule, on-site cleaning takes place after every submersion event

Spectrometer probes, when provided with the right operating conditions (chapter 3.1.2), seem to have a system-inherent self-cleaning tendency, offering the potential of reducing maintenance efforts significantly. But some of the generated data suggests that at a certain point, this self-cleaning effect stops to take effect and more or less permanent encrustations form in the measurement window. One of these instances was captured in a data fragment that was generated after the end of trial programme FIELD 0 in a period during which no on-site maintenance took place. This fragment is depicted in Figure 3-27. The submersion events highlighted Figure 3-27 [2] through Figure 3-27 [4] do not lead to significant plaque removal, despite their considerable water levels. As a consequence, the TSS concentration measured by the spectrometer probe in Figure 3-27 [1] remained at a level between 1000 mg/L and 2000 mg/L. The maximum concentration within the valid measuring range for this parameter, according to the applied global calibration, is 1200 mg/L.

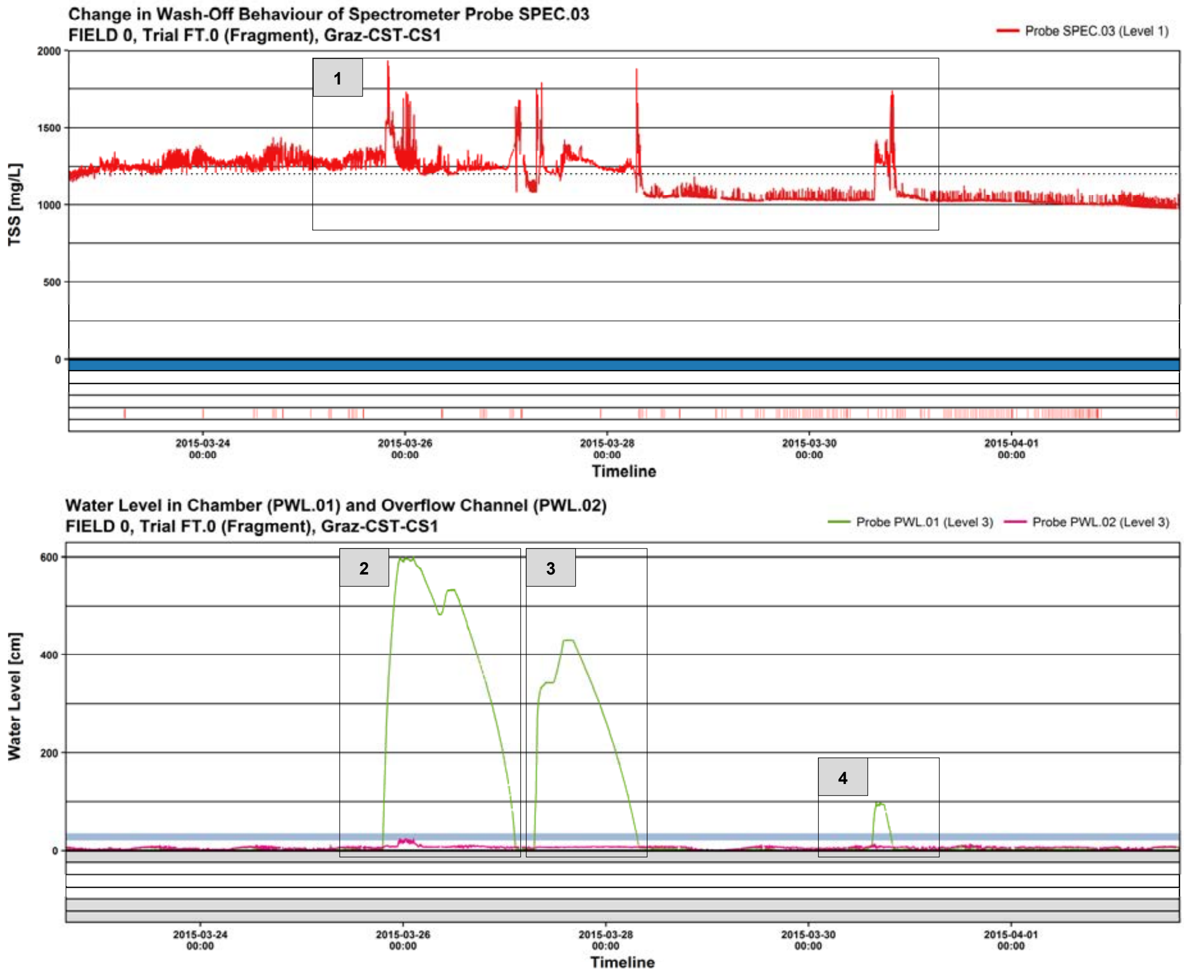

Figure 3-27: Permanent plaque in the optical measurement window of the spectrometer probe during Trial FT.0 of FIELD 0 (fragment) due to poor maintenance efforts during this period

Most of the observed drift and shift patterns of spectrometer probes are caused by accumulation of easily removable residue in the measurement window, which is washed off instantly at the beginning of submersion periods. Given the lack of this wash-off in the data fragment from the CST in Figure 3-27, permanent fouling might nevertheless be a point of concern and deserves further investigation.

Even though the collected data is not sufficient to provide valid information on the key factors leading to permanent fouling, it suggests that there is a certain *concentration* or *fouling threshold* in the form of a more or less stable base line during dry periods, which represents a point-of-no-return, when the system-inherent self-cleaning mechanism ceases to work and plaque remains or continues to be formed in the measurement window. Some data fragments do even suggest an acceleration in plaque formation after a certain level of encrustation is surpassed.

Even though the probe in Figure 3-27 [1] seems to detect the beginning and the end of the depicted submersion periods, the measured TSS concentrations are at the least unreliable, given the typical TSS level during previous events, as provided in the form of time series plots in Appendix C. Since this behaviour was only observed in short fragments of time series after FIELD 0, the generated results do not allow a general determination whether or not such a threshold for permanent fouling exists. As this topic is of interest when reducing probe maintenance on site, it would merit further investigation into the fouling characteristics of the spectrometer probe in station Graz-CST-CS1, once its placement, mounting system and configuration are optimised

It is assumed, that this *fouling threshold* would depend highly on the conditions and the composition of the combined wastewater matrix on site, even for an ideally installed spectrometer probe. Furthermore, higher fouling rates are expected with higher pollutant and particle concentrations. While the threshold for permanent probe fouling is expected to be reached after fewer submersion periods, when concentrations of pollutants and solid fractions in the combined wastewater increase, the duration of submersion periods and the ratio between the duration of submersion and dry periods in systems with alternating operating conditions might be of equal importance for its development.

All of these issues would require additional, targeted investigation. The required insight could be gained efficiently by simultaneous and synchronous operation of two or multiple comparable spectrometer probes under identical conditions and the documentation of their behaviour. In varying the maintenance schedules and maintenance approaches of the probes (e.g. targeted fouling versus regular cleaning), differences in their fouling behaviour could be documented and cross-validated. If only a single spectrometer probe is available in an installation, which it is the case for Graz-CST-CS1, a comparable approach can be chosen to obtain the required information. Such an approach is outlined in the following paragraphs of this chapter. If a threshold for permanent fouling can be defined, the implementation of a demand-driven maintenance concept for spectrometers would be possible, since such a limit would allow the distinction between *irrelevant* fouling patterns, which the system can regulate itself, and *relevant* probe fouling, which requires manual plaque removal. This distinction would have the potential to allow operators to deviate from a fixed maintenance schedule (Figure 3-26), ideally reducing maintenance efforts significantly.

An algorithm to implement a system which can distinguish between relevant and irrelevant fouling of spectrometer probes for the existing equipment in Graz-CST-CS1 is proposed hereinafter.

The proposed approach to implement a condition-based or demand-driven maintenance system in systems with alternating operating conditions, relies on the use of a combination of one or more *indicator probes*, which can reliably and accurately determine the operating state, and a spectrometer probe, the fouling status of which is assessed in order to determine the need for manual cleaning. After the determination and definition of certain thresholds, an alerting system can be implemented. As soon as the generated results of indicator or spectrometer probes surpass critical thresholds, the operator is alerted to the need to maintain the probe on site.

The following paragraphs describe the algorithm to collect the required information to define the required thresholds for the implementation of this condition-based maintenance system for station Graz-CST-CS1. The description of the work flow for the definition of the relevant limits for indicator probes precedes the description for the currently installed single spectrometer probe.

In Figure 3-28 [C] the time series of an *indicator* probe with exposure to the submersion medium is depicted. It is maintained on a fixed schedule. This indicator probe is used to provide a reliable distinction between submersion and dry periods. It can either be a probe which is subjected to the same fouling conditions as the spectrometer probe (e.g. in-line conductivity or temperature probes) or a probe without fouling tendencies like ultrasonic water level or flow rate sensors. Figure 3-28 depicts the first kind of indicator probe. The use of an indicator probe seems to be a more reliable way for distinguishing between submersion periods and dry periods than relying on concentration surges detected by spectrometer probes, in particular when fouling of the spectrometer probe is an issue of concern. Reliable detection of the beginning and the end of submersion periods is crucial information for data collection for the described approach.

Thus, in a first step one or multiple indicator probes are defined. In the case of Graz-CST-CS1, the already installed permanent water level probe above the storage chamber in CS 1 is ideal, since it is not subjected to probe fouling and requires little to no calibration and only little maintenance efforts. Additionally, the conductivity probe placed next to spectrometer probe is also suitable. Though fouling of this probe might be an issue, it operates stable for long periods of time without the need for calibration. Due to its proximity to the spectrometer probe, it can offer information on equipment clogging and the conditions behind the sheet metal cover of the existing installation.

Depending on their placement and type, threshold values for indicator parameters need to be defined (denoted *thr* Figure 3-28 [D]). These thresholds are used to determine whether or not the spectrometer probe is submersed in combined wastewater or operates dryly in the ambient air of the sewer.

Due to their critical role in determining the submersion status of the spectrometer probe, strict maintenance limits (denoted *lim* in Figure 3-28 [D]) for parameters of indicator probes need to be established. This is of particular importance when trying to avoid false positives due to fouling or other damages of these probes. These limits for maintenance should be at a considerable distance to the defined thresholds for the determination of the start or end of submersion periods. Once this limit is defined, a maintenance alert for indicator probes can be implemented. This might only apply to secondary probes subjected to fouling, as depicted in Figure 3-28. The operator receives an alert, once the defined maintenance limit or threshold for fouling of the indicator probe is exceeded over a certain amount of time during a dry period (Figure 3-28 [E]). Maintenance for the indicator probe can scheduled accordingly.

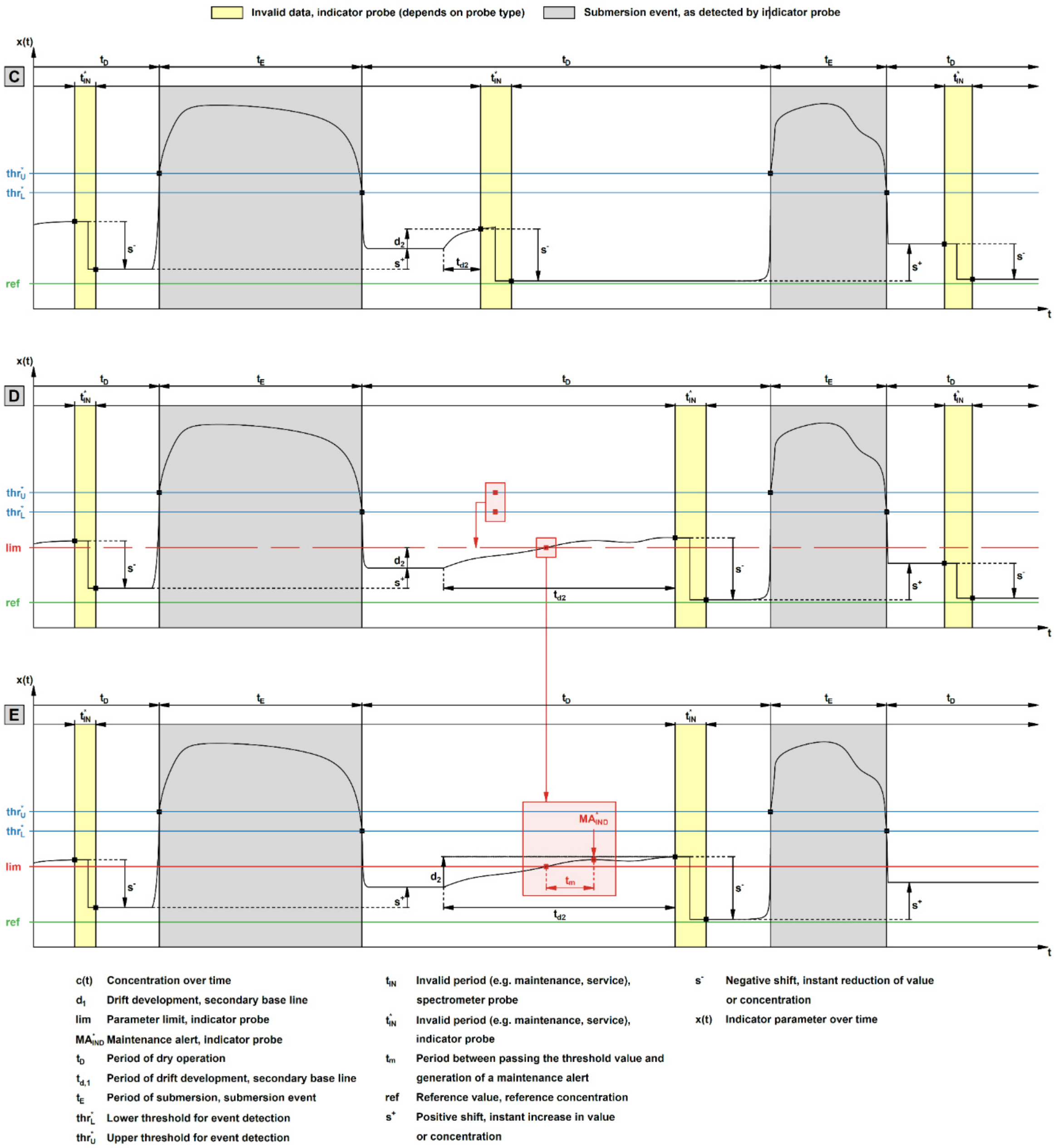

Figure 3-28: Submersion threshold definition and maintenance alert determination for indicator probes

After implementing thresholds for event detection and maintenance alerts for indicator probes, a similar process to collect the required information for spectrometer probes follows. It is designed to determine the concentration limits of parameters like TSS or COD which separate permanent or relevant fouling of the spectrometer in the CST from volatile or irrelevant fouling. The goal is a similar condition-based alerting system for this probe.

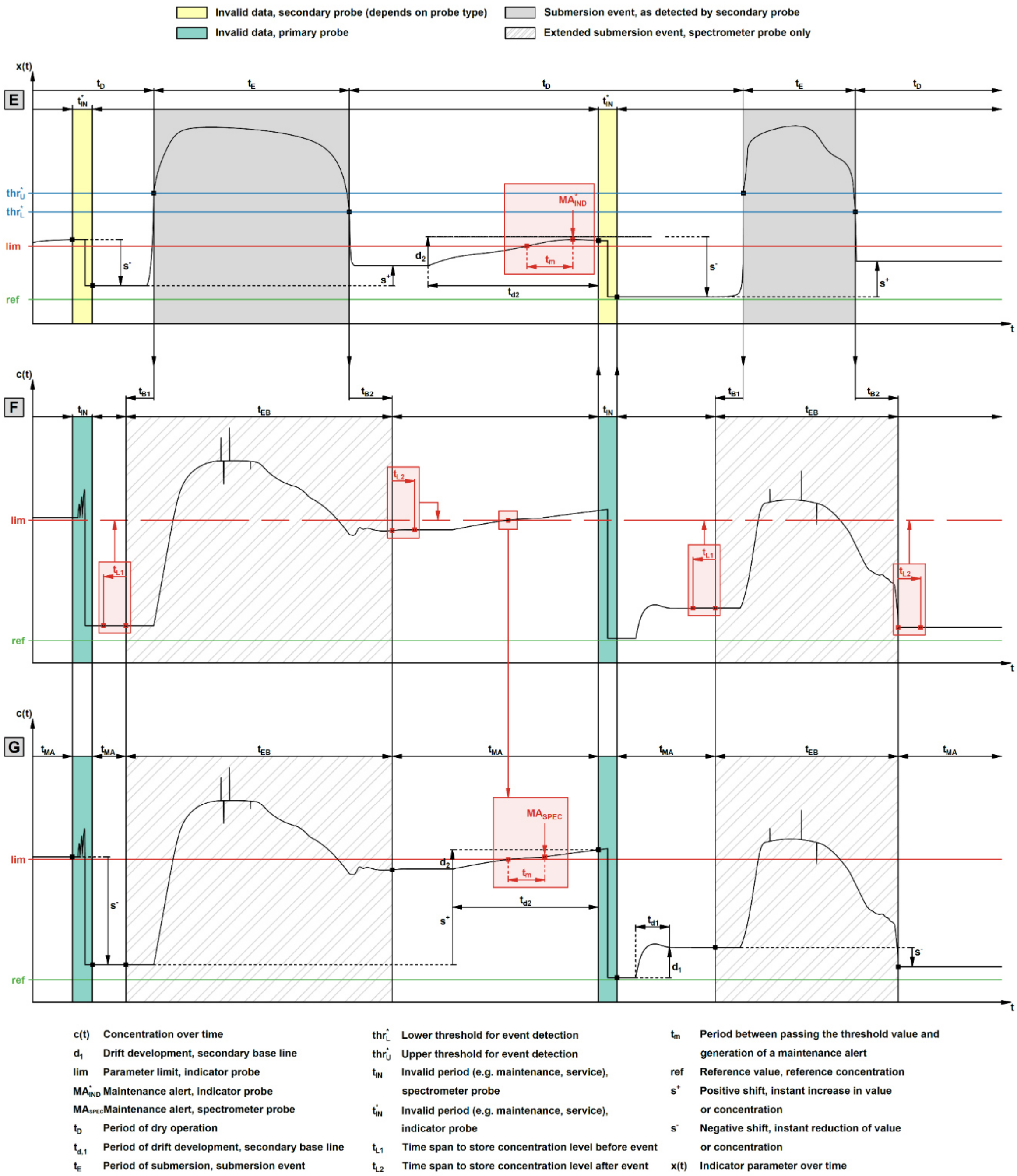

Figure 3-29: Definition of a threshold for permanent fouling and a maintenance alert for spectrometer probes

As a first step in this process, an *extended event duration* is defined for the spectrometer probe. This virtual expansion (Figure 3-29 [F]) of the time span for submersion, as detected by indicator probes (Figure 3-29 [E]), considers the unstable behaviour and effects at the beginning and at the end of submersion events (chapter 3.2). Even though these unstable periods of transition are of interest for the overall time series, they are excluded from this maintenance planning approach, as the characteristics of probe behaviour during these periods might distort the required base lines which are used to identify the threshold concentrations, where irrelevant, volatile fouling turns into relevant, permanent fouling. After excluding the unstable transition phases before and after submersion events, the behaviour of the spectrometer probes during dry operation can be analysed. Time series between the artificially extended submersion periods are at the core of this analysis.

To determine the fouling behaviour of spectrometer probes when only a single probe is available, as is the case in the CST, it is proposed to analyse the average concentration of one or more key sum parameters for certain time slots before and after the virtually extended submersion periods (e.g. the average TSS and COD concentration), as depicted in Figure 3-29 [F]. Through the analysis of concentration levels in these periods, focusing on the extent of shifts due to Wash-Off and other self-cleaning effects in the system for a representative sequence of storage events, threshold concentrations for relevant fouling of the spectrometer probe can be estimated.

When such concentration levels are established, maintenance alerts for the spectrometer probe, similar to the one for indicator probes can be implemented, as depicted in Figure 3-29 [G]. Once the concentration level surpasses the limit for permanent fouling and stays above this limit for a certain period of time, the operator is alerted to the need of maintenance on site, which can be scheduled after a review of the data preceding the alert.

After the placement, mounting system and configuration of the in-line equipment at monitoring station Graz-CST-CS1 is optimsed in accordance with section 3.4.1, the proposed algorithm to define the thresholds at the core of this condition-based manintenace approach can be implemented. Testing of the concept will provide insight in its effectiveness regarding the quality of the generated data, a possisble reduction in maintenance costs and the expected increase in satefy for the maintenance staff.

4 Summary and Outlook

As intended, this work used already recorded time series from an inflexible-installed water quality monitoring station operated under alternating operating conditions in the Central Storage Tunnel CST in Graz, Austria (FIELD 0), as starting point for the design of a series of laboratory experiments (LAB 1 and LAB 2), trying to replicate the conditions on site. In addition, a field testing programme (FIELD 1) was conducted with a flexible installation under similar alternating operating conditions. While the laboratory experiments were designed to emulate the conditions in the CST and the constraints induced by the existing installation as close as possible, FIELD 1 was aimed at substantiating preliminary findings and gaining insight in the possible use of alternative installation designs in the CST.

The overall objective of the conducted investigations was the identification of reasons for negative behaviour of in-situ, online spectrometer probes exposed to a sequence of continuous changes between being submerged in combined wastewater and operated in the ambient air of the sewer. An extensive set of metadata and the use of multiple probes and measuring systems allowed the pinpointing of behavioural characteristics in the time series of spectrometer probes when subjected to said conditions. To establish links between the sources of negative probe behaviour and their characteristic manifestations in the generated time series, a set of criteria was defined and combined in a visualisation concept in the form of static figures used to analyse the results.

Once cause-and-effect relations between patterns in the time series of spectrometer probes indicating negative behaviour and the probe's placement, mounting system, configuration and operation were identified, measures to prevent these patterns from occurring on site were developed. Even when considering the limitations of the experiments and field testing programmes, the generated data suggests that a multitude of findings can be transferred to operation of the installed equipment in the CST. The proposed changes are aimed at maximising the quality of the generated data, ideally while reducing maintenance efforts in the process. Measures to adapt the current installation and optimise the configuration of the equipment of station Graz-CST-CS1 accordingly, were not implemented by the time this thesis was submitted, since regular operation of both the CST and the monitoring installation had not yet commenced.

As a consequence, final confirmation of the effectiveness of the proposed measures on the quality of generated time series and future maintenance efforts cannot be provided. Nonetheless, all research questions posed in chapter 1.5 were answered in the affirmative, thus corroborating the underlying hypotheses. Hence it is expected, that the changes to the equipment in the CST derived from this thesis will reduce interference of the mounting system and in-line probes on the generated data during submersion events.

Once probe operation is optimised by implementing the measures proposed in section 3.4.1, the focus can shift towards reducing maintenance efforts. In chapter 3.4.2 an algorithm is proposed to implement a condition-based maintenance system for the spectrometer probe of station Graz-CST-CS1. The algorithm is based on findings from the field and laboratory trials for this thesis, which suggest that a threshold for critical probe fouling can be defined. The data leads to the assumption that plaque, as long as its level stays under a critical threshold, is washed-off easily from the measurement window of spectrometer probes and does not necessarily lead to low data quality during submersion periods. This form of probe fouling is considered irrelevant fouling. Once the level of plaque and encrustations has surpassed the threshold, it is no longer washed-off at the beginning of submersion periods, thereby leading to invalid results. This form of probe fouling is considered relevant fouling.

The outlined algorithm describes a way to collect the necessary information to implement a system that can evaluate the degree of probe fouling during periods of dry fall. If the concentration levels of specific parameters (e.g. TSS or COD) stay above the defined threshold for a certain amount of time - indicating relevant fouling - the operator is alerted to the need for probe maintenance on site. Otherwise it can be assumed that plaque or encrustations on the measurement window are volatile and removed instantly at the beginning of the next submersion period and do not constitute a need for on-site maintenance. While this algorithm to implement condition-based maintenance is based on the equipment available at station Graz-CST-CS1, it can be altered and applied to other monitoring installations with a spectrometer probe and similar operating conditions. The goal of the proposed concept for condition-based maintenance is to reduce costs and increase safety for the in-line operation of spectrometer probes in systems with complex operating conditions. Similar to the changes proposed for the placement, mounting and configuration of the station, the implementation and testing of the oulined algorithm was not possible, since Graz-CST-CS1 was not fully operational by the time this thesis was submitted.

In conclusion, this work showed that the application of a structured approach combining field testing and laboratory experiments can be applied to pinpoint the sources of neagtive and positive probe behaviour by an in-depth analysis of the time series of spectrometer probes operated in systems with alternating operating condtions. Once those sources are defined, changes to the placement, mounting concept and configuration of these probes can be implemented to increase data quality and reduce the need for on-site maintenance. While the findings of this thesis are focused on an existing monitoring station in the CST, they can be transferred to other monitoring sites with similar operating condtions. As a whole, the implementation of the proposed measures has the potential to increase both the effectiveness and efficiency of in-line online monitoring with spectrometer probes in sewers and storage tunnels.

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Appendix

This appendix is comprised of three subsections. While Appendix A is part of this hard copy, Appendices B and C are provided as digital copies only. This hard copy contains file trees for the contents of Appendix B and Appendix C respectively.

Appendix A

Appendix A contains timelines and operational data in tabular from and drawings of the equipment and setups used during laboratory and field trials. This section of the appendix also provides tables and exemplary figures detailing the aspects and elements of the concept for result visualisation.

Appendix B

The second subsection of the Appendix contains all the generated data from laboratory experiments and field testing campaigns, in raw and processed form, as well the *R*-scripts used to process it.

Appendix C

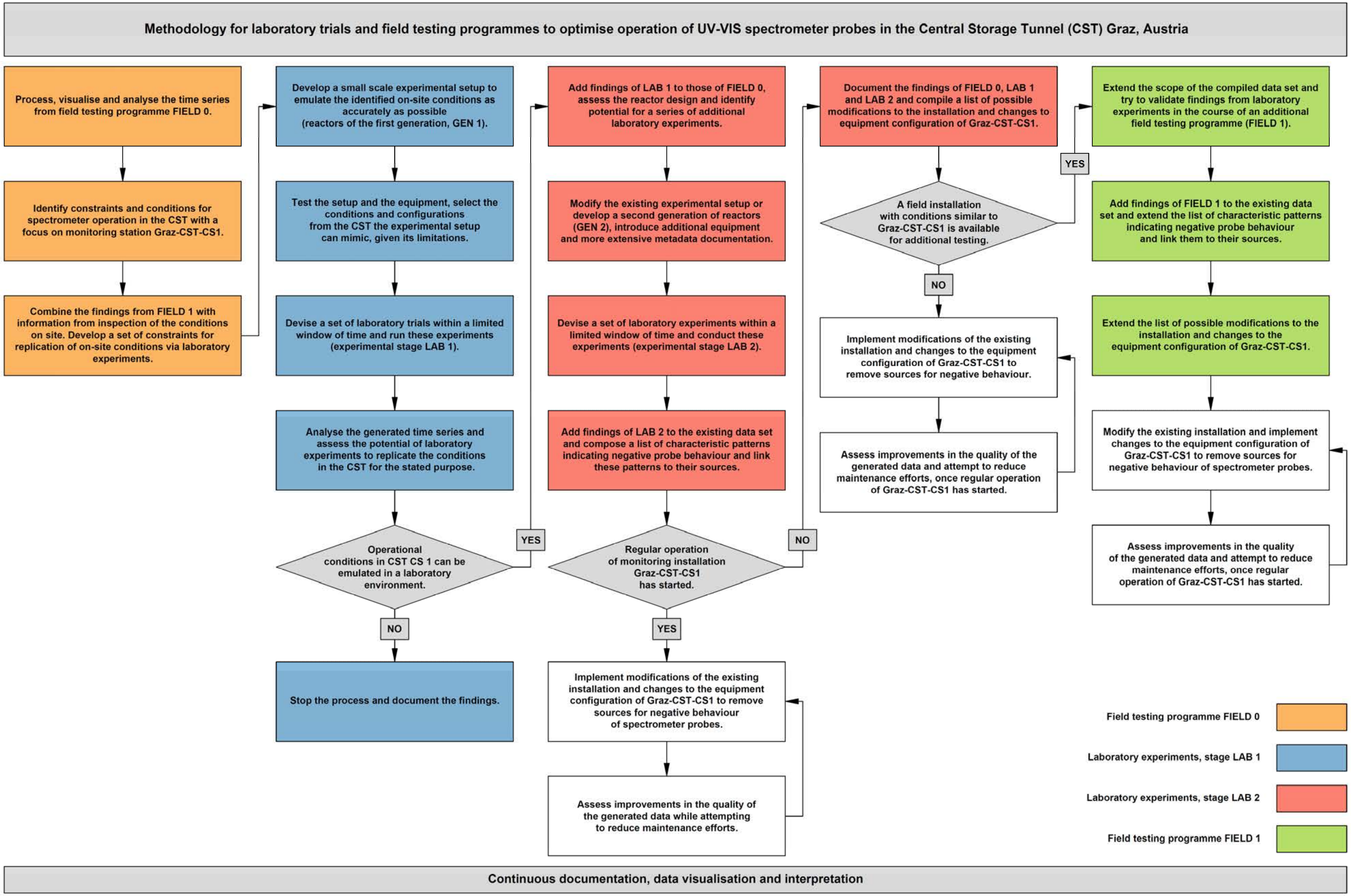
The final subsection of the Appendix is comprised of the plots used for data analysis, the *R*-scripts to generate them and all other media files (figures, photos and videos) generated in the course of laboratory and field work.

Appendix B and Appendix C are combined on a single storage medium, supplied at the end of this work.

Appendix A

Appendix A contains a detailed flow chart of the applied methodology, tables on operational settings, equipment configurations and probe placement grids for all field and laboratory trials. The respective information is combined for laboratory experiments of LAB 1 and LAB 2, ahead of a block for field testing programmes FIELD 0 and FIELD 1.

A.0 Methodology flow chart



A.1 Equipment and chemical analyses

The following tables detail the probes, control units, data loggers and additional equipment used while conducting laboratory trials of stages LAB 1 and LAB 2, as well as field testing campaigns FIELD 0 and FIELD 1.

Another set of tables outlines analytical programmes and details applied chemical analyses.

A.1.1 Control units and data loggers

Control Units and Data Loggers							
Equipment Data				Laboratory Trial Programme		Field Testing Programme	
Identification	Serial Number	Controller / Logger	Manufacturer	LAB 1	LAB 2	FIELD 0	FIELD 1
CS.01	11240321	con::stat	s::can	x	x	-	-
CS.02	11240322	con::stat	s::can	x	x	-	-
CC.01	12120012	con::cube	s::can	-	x	-	-
CC.02	11190022	con::cube	s::can	-	x	-	-
CC.04	12130005	con::cube	s::can	-	-	-	x
CC.05	12360015	con::cube	S::can	-	-	x	
SCM.01	1200134 (1225086)	SC 1000 (display)	Hach Lange	-	x	-	-
HQ40.01	70800011300	HQ40d	Hach Lange	-	x	-	-
MULTI.01	14410743	Multi 3430	WTW	x	x	-	-
MULTI.02	10481771	Multi 3430	WTW	-	x	-	-
OCM.01	1119PRC1897	OCM PRO OCP	Nivus	-	-	-	x
NVM.01	not available	NivuMaster 3	Nivus	-	-	x	-
NVM.02	not available	NivuMaster 3	Nivus	-	-	x	-

A.1.2 Primary (PRI) probes

Primary (PRI) Probes										
Probe Data							Laboratory Trial Programme		Field Testing Programme	
Identification	Serial Number	Type	Manufacturer	OPL [mm]	Global Calibration	Reference	LAB 1	LAB 2	FIELD 0	FIELD 1
SPEC.01	11280194	spectro::lyser V1	s::can	5	INFLU004V16T	Dist_H2O	x	-	-	-
SPEC.02	11280204	spectro::lyser V1	s::can	5	INFLU004V16T	Dist_H2O	x	x	-	-
SPEC.03	10230056	spectro::lyser V1	s::can	2	INFLU004V16T	Dist_H2O	-	x	x	-
SPEC.04	12150088	spectro::lyser V2	s::can	5	INFLU004V16T	Dist_H2O	-	x	-	-
SPEC.05	12150407	spectro::lyser V2	s::can	5	INFLU004V16T	Dist_H2O	-	-	-	x
ISCAN.01	15090009	i::scan	s::can	5	Y11-3-I-075	Dist_H2O	-	x	-	-
ISCAN.02[1)]	13330004	i::scan	s::can	5	confidential	confidential	-	x	-	-
[1)] This probe was provided for testing purposes only. The generated data was redacted in compliance with an agreement with the manufacturer.										

A.1.3 Secondary (SEC) probes

Secondary (SEC) Probes									
Probe Data						Laboratory Trial Programme		Field Testing Programme	
Identifica-tion	**Serial Number**	**Type**	**Manufacturer**	**Global Calibration**	**Reference**	**LAB 1**	**LAB 2**	**FIELD 0**	**FIELD 1**
SOLI.01	1341	soli::lyser, E-505-2-075, OPL 25 mm	s::can	factory calibrated	-	-	-	**x**	-
COND.01	3487	condu::lyser V1	s::can	factory calibrated	-	-	-	**x**	-
ST.01	1128307	Solitax SC ts-line	Hach Lange	formazin stand-ard	distilled water	-	**x**	-	-
ST.02	1128308	Solitax SC ts-line	Hach Lange	formazin stand-ard	distilled water	-	**x**	-	-
ST.03	1301468	Solitax SC ts-line	Hach Lange	formazin stand-ard	distilled water	-	**x**	-	-
LDO.01	72012598505	LDO101	Hach Lange	factory calibrated	-	-	**x**	-	-
LDO.02	72052598566	LDO101	Hach Lange	factory calibrated	-	-	**x**	-	-
FDO.01	14380385	FDO 925-3	WTW	factory calibrated	-	-	**x**	-	-
FDO.02	10410455	FDO 925-3	WTW	factory calibrated	-	-	**x**	-	-
EC.01	10360107	TetraCon 925-3	WTW	factory calibrated	-	**x**	**x**	-	-
EC.02	14390626	TetraCon 925-3	WTW	factory calibrated	-	-	**x**	-	-
PH.01	C112105006	SenTix 940-3	WTW	initial calibration	WTW Technical Buffer Solution	**x**	**x**	-	-
PH.02	C142711045	SenTix 940-3	WTW	initial calibration	WTW Technical Buffer Solution	-	**x**	-	-
OCL.01	1544PL20423	OCL-L1	Nivus	initial calibration on site by manufacturer	-	-	-	-	**x**
POA.01	1619PK33098	POA-V2D0	Nivus	initial calibration on site by manufacturer	-	-	-	-	**x**
PWL.01	k0ks1ml01[1)]	P-Series (10/15)[2)]	Nivus	initial calibration	-	-	-	**x**	-
PWL.02	k0ks1ml02[1)]	P-Series (10/15)[2)]	Nivus	initial calibration	-	-	-	**x**	-
FLOD.01	7N7190862001	FLO-DAR AV	Hach	initial calibration	-	-	-	**x**	-
PS.01	AT47003B-49-16-0160	3100B0010B000RS	Gems Sensors & Controls	factory calibrated	-	-	-	**x**	**x**
PS.02	not available	not available	Gems Sensors & Controls	factory calibrated	-	-	**x**	-	-

1) These numbers refer to the indexing system of probes in the process control system of WWTP Graz and do not represent actual serials.
2) The exact probe type was not known by the time this thesis was submitted.

A.1.4 Parameters monitored by primary and secondary probes

Parameter Overview for Primary (PRI) and Secondary (SEC) Probes																
Probe Data		Turbidity	TSS[1]	COD[1]	CODf[1]	BOD[1]	TOC[1]	DOC[1]	NO_3-N[1]	DO	EC	T	pH	Q	h	P
Probe ID	Category	FNU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µS/cm	°C	-	L/s	cm	bar
SPEC.01	PRI	-	x	x	x	x	x	x	x	-	-	x	-	-	-	-
SPEC.02	PRI	-	x	x	x	x	x	x	x	-	-	x[2]	-	-	-	-
SPEC.03	PRI	-	x	x	x	x	x	x	x	-	-	x	-	-	-	-
SPEC.04	PRI	-	x	x	x	x	x	x	x	-	-	x	-	-	-	-
SPEC.05	PRI	-	x	x	x	x	x	x	x	-	-	x	-	-	-	-
ISCAN.01	PRI	-	x	x	x	-	-	-	-	-	-	x	-	-	-	-
ISCAN.02	PRI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SOLI.01	SEC	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-
COND.01	SEC	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-
ST.01	SEC	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ST.02	SEC	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ST.03	SEC	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LDO.01	SEC	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-
LDO.02	SEC	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-
FDO.01	SEC	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-
FDO.02	SEC	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-
EC.01	SEC	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-
EC.02	SEC	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-
PH.01	SEC	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-
PH.02	SEC	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-
OCL.01	SEC	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
POA.01	SEC	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-
PWL.01	SEC	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-
PWL.02	SEC	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-
FLOD.01	SEC	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
PS.01	SEC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x
PS.02	SEC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x

[1] Results for these sum parameters are provided as equivalent concentrations by spectro::lyser and i::scan probes.
[2] Temperature results for probe SPEC.02 was only generated during trials of LAB 2.

A.1.5 Chemical analyses, methods and procedures

Parameter	Analytical Method	Code or Standard for the Procedure	Description of Analytical Procedures	Minimum Sample Volume for Single Determination [mL]
TSS	**tss.01**	DIN 38409-H2	The total suspended solids (TSS) in a mechanically homogenised sample (minimum sample volume of 250 mL at 38 000 rpm via Ultra-Turrax) are determined via pressure filtration with tap water (8 bar service pressure), through a cellulose filter with an aperture of 45 µm, followed by weighing the dried filter (drying oven, 105°C) before and after the filtration process. The difference in filter-weights translates to the TSS concentration in the sample.	50 (influent), 200 (effluent)
COD	**cod.01**	Manual	The chemical oxygen demand (COD) of a mechanically homogenised sample (minimum sample volume of 250 mL at 38 000 rpm via Ultra-Turrax) is determined by means of a spectrophotometric vial test by company Hach Lange. The following vials were used for expected COD concentrations in brackets: LCK 1414 (5 - 60 mg/L), LCK 314 (15 -150 mg/L), LCK 114 (150 - 1000 mg/L) or LCK 714 (100 - 600 mg/L). Samples are prepared and analysed in accordance with the manual. A HT200S high-temperature thermostat, as well as a field photometer by Hach Lange is used in the process.	2
CODf	**codf.01**	Manual	The chemical oxygen demand of a filtered sample (CODf) is determined by means of a spectrophotometric vial test by Hach Lange. The sample, which is a by-product of the filtration process of TSS-determination, is prepared and analysed in accordance with manual and with the same process and equipment as described for COD determination. The following vials were used for expected CODf concentrations in brackets: LCK 1414 (5 - 60 mg/L), LCK 314 (15 -150 mg/L), LCK 114 (150 - 1000 mg/L) or LCK 714 (100 - 600 mg/L).	97 (influent), 432 (effluent)
NO_3-N	**no3.01**	Manual	The nitrate-nitrogen concentration of the mechanically homogenised (minimum sample volume of 250 mL at 38 000 rpm, Ultra-Turrax) sample is determined by means of a spectrophotometric vial test by Hach Lange. Only one vial type, LCK 339, for expected concentrations between 0.23 - 13.5 mg/L was used. Samples are prepared and analysed in accordance with the manual. A HT200S high-temperature thermostat, as well as a field photometer by Hach Lange is used in the process.	1
BOD_5	**bod.01**	Manual	The biochemical oxygen demand after five days of a mechanically homogenised sample (minimum sample volume of 250 mL at 38 000 rpm, Ultra-Turrax) is determined by use of the Oxitop Control system by company WTW, measuring the pressure development in a closed system over or respectively after 5 days.	20
TOC	**toc.01**	ÖNORM EN 1484	Total organic carbons in the mechanically homogenised sample (minimum sample volume of 250 mL at 38 000 rpm, Ultra-Turrax) are determined via combustion catalytic oxidation in Shimadzu TOC analyser according to the given standard.	20
DOC	**doc.01**	ÖNORM EN 1484	Dissolved organic carbons in the mechanically homogenised (minimum sample volume of 250 ml at 38 000 rpm) sample are determined via combustion catalytic oxidation in Shimadzu TOC analyser, according to the given standard.	20
EC	**ec.01**	Manual	The electric conductivity of a sample is determined directly after grabbing or drawing the sample, with handheld lab probe EC.01, connected to the control unit MULTI.01.	-
T	**temp.01**	Manual	The temperature of a sample is determined directly after grabbing or drawing the sample, with handheld lab probe EC.01, connected to the control unit MULTI.01	-
PH	**ph.01**	Manual	The ph-value of a sample is determined directly after grabbing or drawing the sample, with handheld lab probe PH.01, connected to the control unit MULTI.01.	-

A.1.6 Analytic programmes

Analytic Programme	(Sum) Parameter for Sample Characterisation												
	Sample Volumes [mL]			Number of Independent Determinations by Utilised Method									
	Standard	Minimum	Maximum	tss.01	cod.01	codf.01	bod.01	toc.01	doc.01	no3.01	ec.01	temp.01	ph.01
AP 1	1500	1500	-	3	3	3	3	5	5	-	1	1	1
AP 2	400	250	1200	3	3	3	-	5	5	-	1	1	1
AP 3	900	250	-	2	2	2	-	-	-	-	-	-	-
AP 4	1500	250	-	2	2	2	2	2	2	2	-	-	1

A.2 Data visualisation concept

The following section is intended to provide an overview of abbreviations, colour schemes and plot concepts used in visualising and interpreting the generated time series.

Both, the abbreviations and the colour scheme were uniformly applied to all plots and tables in this thesis.

A.2.1 Abbreviations and colours used in figures and tables

Abbreviations and Colour Scheme for Tables and Graphic Representations of Data					
Significance, Description	**Abbrevia-tion**	**Colour Representation, Codes (HEX, RGB) and Transparency (α) in Percent**			
		-	**HEX**	**RGB**	**α [%]**
Automatic probe cleaning settings	**APCS**	-	-	-	-
Chamber	**CH**	-	-	-	-
Control room at station Graz-CST-CST or control panel in the control cabi-net at station Graz-WWTP-CSO	**CR**	-	-	-	-
Control structure CS 1 of the CST Graz, Austria	**CS 1**	-	-	-	-
Combined sewer overflow	**CSO**	-	-	-	-
Central Storage Tunnel Graz, Austria	**CST**	-	-	-	-
Reactor generation	**GEN**	-	-	-	-
Immersion reactor - probe is partially immersed in the sample/medium (GEN 1-reactors)	**IMM**	-	-	-	-
Manual operation of agitation system	**MO**	-	-	-	-
Agitation by magnetic stirrer (GEN 1-reactors)	**MS**	-	-	-	-
Overflow channel	**OV**	-	-	-	-
Primary probe	**PRI**	-	-	-	-
Agitation by aerating the reactor with compressed air from the bottom (GEN 2-reactors)	**RA**	-	-	-	-
Secondary probe	**SEC**	-	-	-	-
Submersion reactor - probe is entirely submersed in the medium/sample (GEN 2-reactors)	**SUB**	-	-	-	-
Operation of agitation system via timer clock	**TC**	-	-	-	-
Wastewater treatment plant	**WWTP**	-	-	-	-
Ambient air	**AIR**		#ffffff	255,255,255	0
Combined wastewater substitute	**CWS**		#d9d9d9	217,217,217	50
Combined wastewater	**CWW**		#d9d9d9	217,217,217	0
Special operating conditions	**SOC**		#e5c494	229,196,148	50
Automatic probe cleaning activated	**ON**		#1f78b4	31,120,180	0
Automatic probe cleaning deactivated	**OFF**		#a6cee3	166,206,227	0
Reactor agitation activated	**ON**		#33a02c	51,160,44	0
Reactor agitation deactivated	**OFF**		#b2df8a	178,223,138	0
Manipulation of the system	**MAN**		#e31a1c	227,26,28	0
No manipulation of the system	**-**		#fb9a99	251,154,153	0
Stable operating conditions	**STB**		#ffff99	255,255,153	0
Charging (filling) of the reactor	**CHG**		#fdbf6f	253,191,111	0

continued on next page

continued from previous page					
Discharging (emptying) of the reactor	**DIS**		#ff7f00	255,127,0	0
No data for operational status available	**-**		#d9d9d9	217,217,217	0
Equipment installation	**INS**		#fdb462	253,180,98	0
Replacement of wear parts, components, etc.	**RPL**		#80b1d3	128,177,211	0
Equipment service (e.g. discharge of maintenance unit)	**SER**		#b3de69	179,222,105	0
Repair works (on probes and mounting systems)	**REP**		#fb8072	251,128,114	0
No manual probe cleaning	**NC**		#e41a1c	228,26,28	0
Manual probe cleaning, intensive cleaning standard	**IC**		#4daf4a	77,175,74	0
Visual inspection	**VI**		#377eb8	55,126,184	0
Removal of material (e.g. hygiene products)	**RM**		#ffed6f	255,237,111	0
No feasible data (system not installed yet, or currently not installed)	**NFD**		#8dd3c7	141,211,199	50
No check valve installed	**NV**		#fff2ae	255,242,174	0
Check valve installed	**CV**		#fdcdac	253,205,172	0
Tap water	**TW**		#cbd5e8	203,213,232	0
Compressed air	**CA**		#b3e2cd	179,226,205	0
Measuring interval and target values (service pressure, submersion threshold during FIELD 1)	**-**		#4575b4	69,117,180	0
Area of approximate submersion threshold for probes of station Graz-CST-CS 1 during FIELD 0	**-**		#4575b4	69,117,180	50
Measuring interval over target, identical consecutive measurements	**-**		#d73027	215,48,39	0
					end of table

A.2.2 Visualisation concept for laboratory trial programmes LAB 1 and LAB 2

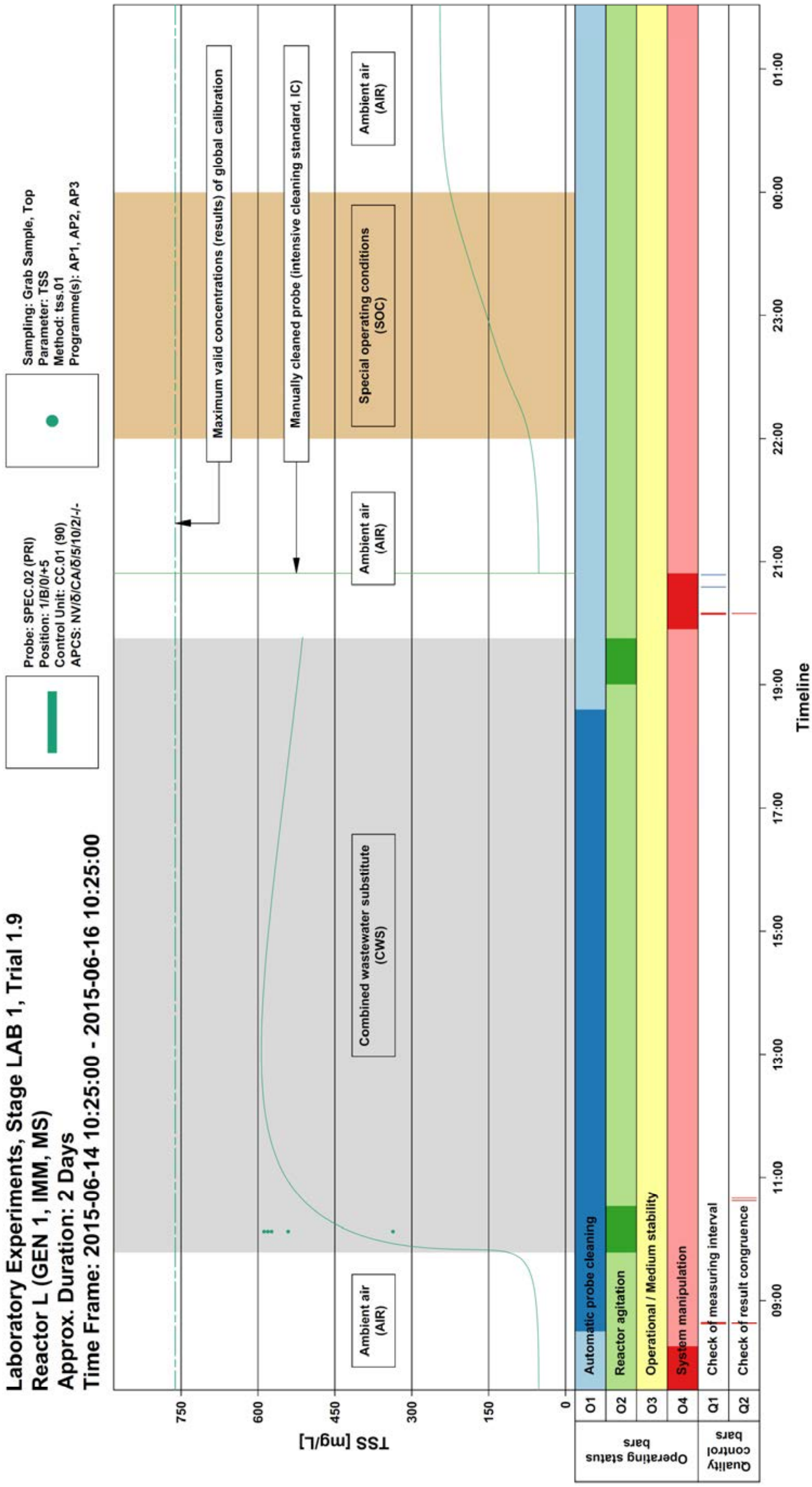
A.2.2.1 Colour scheme for operating status bars and quality control bars

Colour Scheme for Operating Status Bars and Quality Control Bars for Laboratory Trial Programmes LAB 1 and LAB 2				
Status Bar		Significance	Colour	Significance
Operating Status	O1	Automatic Probe Cleaning		Automatic probe cleaning activated
				Automatic probe cleaning deactivated
				No automatic probe cleaning data available
	O2	Reactor Agitation		Reactor agitation on
				Reactor agitation off
				No reactor agitation data available
	O3	Operational/ Medium Stability		Stable operating conditions
				Charging of the reactor
				Discharging of the reactor
				No operational stability data available
	O4	System Manipulation		Manipulation of the system
				No manipulation of the system
				No system manipulation data available
Quality Control	Q1	Check of Measuring Interval		Measuring interval meets target interval
				Measuring interval over target interval
				Measuring interval under target interval
	Q2	Check of Result Congruence		Consecutive measurements deviating
				Consecutive measurements identical

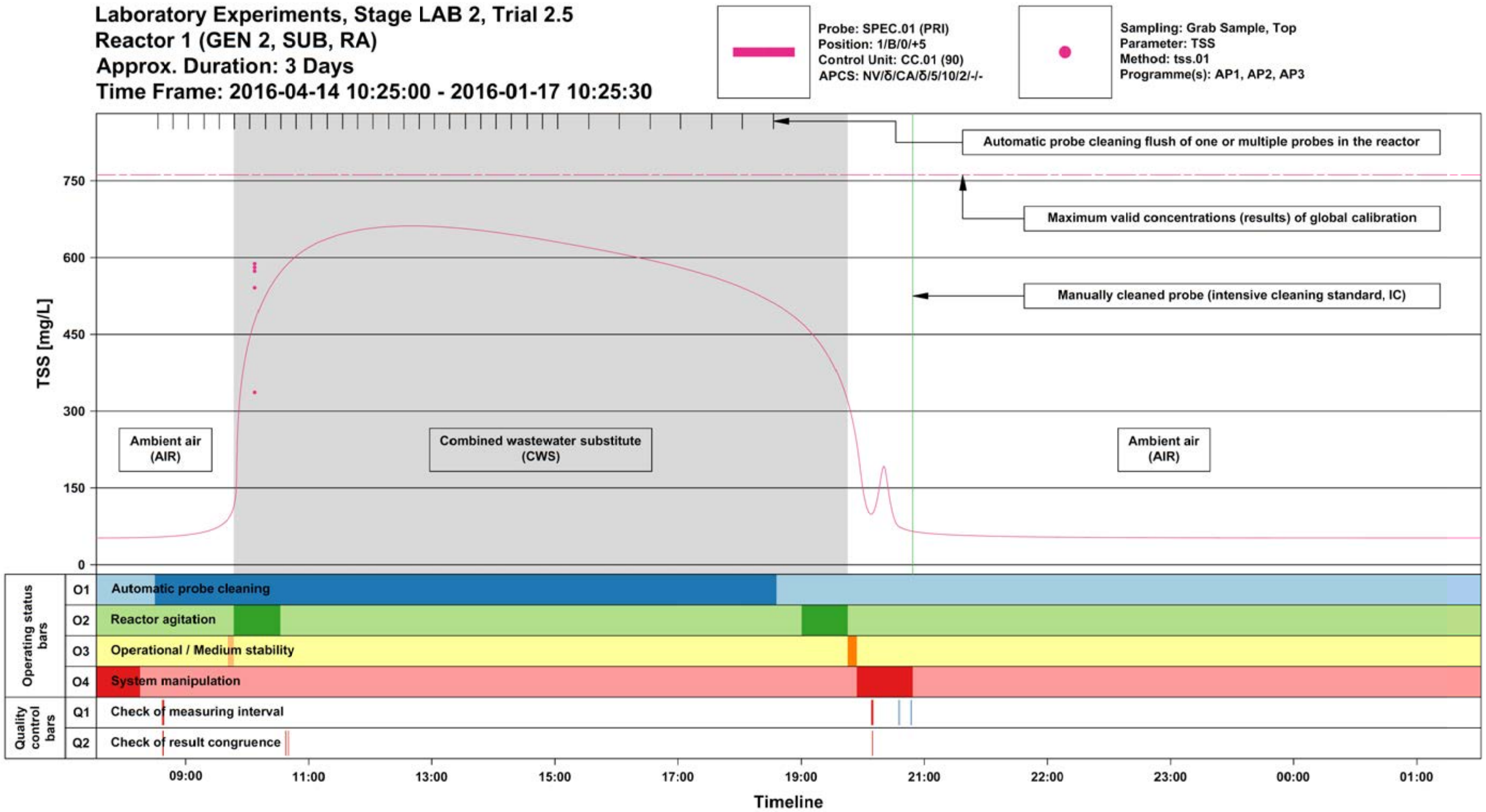
A.2.2.2 Example figures

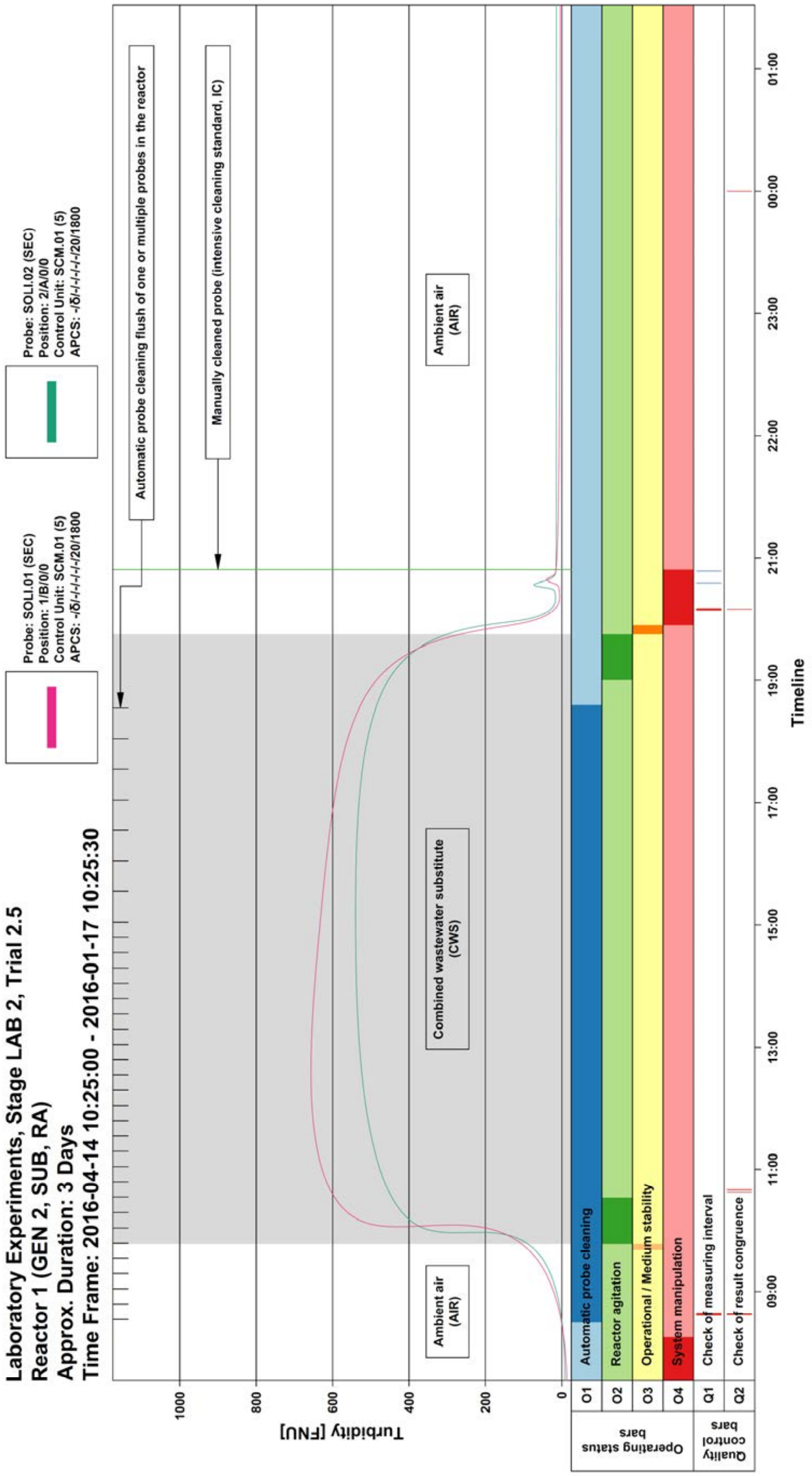
The following four figures illustrate the elements used to display the generated time series during laboratory experiments of stages LAB 1 and LAB 2. The four operating status bars highlighting the operating state throughout a trial and the two quality control bars, introduced in chapter 2.9, are placed at the bottom of the time series visualisation (main section of the figures).

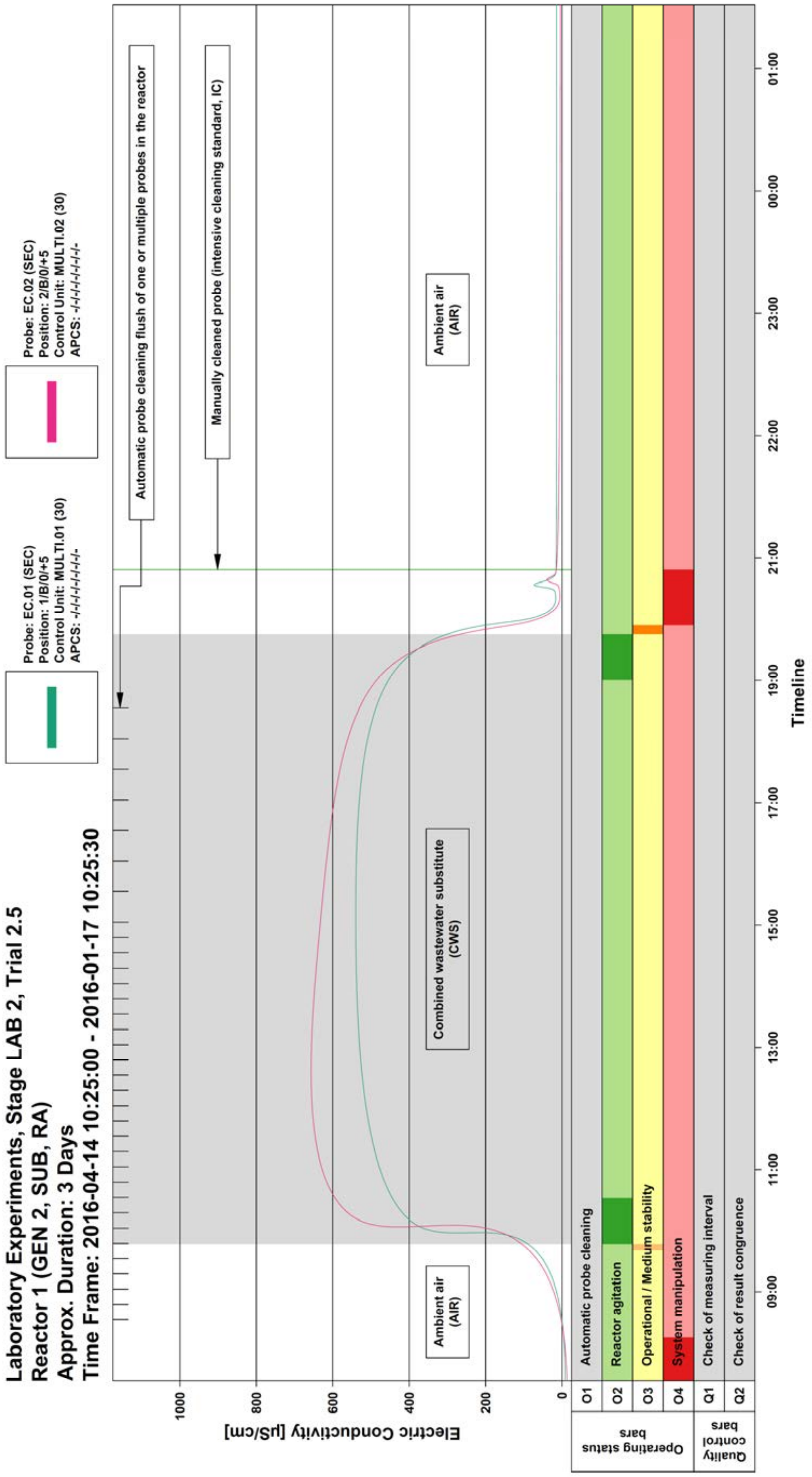
Background shades represent the immersion or submersion medium of the probes. Additional elements are marked and explained in the following figures.



Laboratory Experiments, Stage LAB 1, Trial 1.9
Reactor L (GEN 1, IMM, MS)
Approx. Duration: 2 Days
Time Frame: 2015-06-14 10:25:00 - 2015-06-16 10:25:00
Probe: SPEC.02 (PRI)
Position: 1/B/0/+5
Control Unit: CC.01 (90)
APCS: NV/δ/CA/δ/5/10/2/-/-
Sampling: Grab Sample, Top
Parameter: TSS
Method: tss.01
Programme(s): AP1, AP2, AP3
Maximum valid concentrations (results) of global calibration
Manually cleaned probe (intensive cleaning standard, IC)
Ambient air (AIR)
Combined wastewater substitute (CWS)
Ambient air (AIR)
Special operating conditions (SOC)
Ambient air (AIR)
TSS [mg/L]
750
600
450
300
150
0
Operating status bars
O1
Automatic probe cleaning
O2
Reactor agitation
O3
Operational / Medium stability
O4
System manipulation
Quality control bars
Q1
Check of measuring interval
Q2
Check of result congruence
09:00
11:00
13:00
15:00
17:00
19:00
21:00
22:00
23:00
00:00
01:00
Timeline


Laboratory Experiments, Stage LAB 2, Trial 2.5
Reactor 1 (GEN 2, SUB, RA)
Approx. Duration: 3 Days
Time Frame: 2016-04-14 10:25:00 - 2016-01-17 10:25:30
Probe: SPEC.01 (PRI)
Position: 1/B/0/+5
Control Unit: CC.01 (90)
APCS: NV/δ/CA/δ/5/10/2/-/-
Sampling: Grab Sample, Top
Parameter: TSS
Method: tss.01
Programme(s): AP1, AP2, AP3
Automatic probe cleaning flush of one or multiple probes in the reactor
Maximum valid concentrations (results) of global calibration
Manually cleaned probe (intensive cleaning standard, IC)
TSS [mg/L]
750
600
450
300
150
0
Ambient air (AIR)
Combined wastewater substitute (CWS)
Ambient air (AIR)
Operating status bars
O1 Automatic probe cleaning
O2 Reactor agitation
O3 Operational / Medium stability
O4 System manipulation
Quality control bars
Q1 Check of measuring interval
Q2 Check of result congruence
09:00
11:00
13:00
15:00
17:00
19:00
21:00
22:00
23:00
00:00
01:00
Timeline


Laboratory Experiments, Stage LAB 2, Trial 2.5
Reactor 1 (GEN 2, SUB, RA)
Approx. Duration: 3 Days
Time Frame: 2016-04-14 10:25:00 - 2016-01-17 10:25:30
Probe: SOLI.01 (SEC)
Position: 1/B/0/0
Control Unit: SCM.01 (5)
APCS: -/δ/-/-/-/-/20/1800
Probe: SOLI.02 (SEC)
Position: 2/A/0/0
Control Unit: SCM.01 (5)
APCS: -/δ/-/-/-/-/20/1800
Automatic probe cleaning flush of one or multiple probes in the reactor
Manually cleaned probe (intensive cleaning standard, IC)
Ambient air
(AIR)
Combined wastewater substitute
(CWS)
Ambient air
(AIR)
Turbidity [FNU]
1000
800
600
400
200
0
Operating status bars
O1
Automatic probe cleaning
O2
Reactor agitation
O3
Operational / Medium stability
O4
System manipulation
Quality control bars
Q1
Check of measuring interval
Q2
Check of result congruence
09:00
11:00
13:00
15:00
17:00
19:00
21:00
22:00
23:00
00:00
01:00
Timeline



Laboratory Experiments, Stage LAB 2, Trial 2.5
Reactor 1 (GEN 2, SUB, RA)
Approx. Duration: 3 Days
Time Frame: 2016-04-14 10:25:00 - 2016-01-17 10:25:30
Probe: EC.01 (SEC)
Position: 1/B/0/+5
Control Unit: MULTI.01 (30)
APCS: -/-/-/-/-/-/-/-
Probe: EC.02 (SEC)
Position: 2/B/0/+5
Control Unit: MULTI.02 (30)
APCS: -/-/-/-/-/-/-/-
Automatic probe cleaning flush of one or multiple probes in the reactor
Manually cleaned probe (intensive cleaning standard, IC)
Ambient air
(AIR)
Combined wastewater substitute
(CWS)
Ambient air
(AIR)
Electric Conductivity [µS/cm]
1000
800
600
400
200
0
Operating status bars
O1
O2
O3
O4
Automatic probe cleaning
Reactor agitation
Operational / Medium stability
System manipulation
Quality control bars
Q1
Q2
Check of measuring interval
Check of result congruence
09:00
11:00
13:00
15:00
17:00
19:00
21:00
22:00
23:00
00:00
01:00
Timeline

A.2.3 Visualisation concept for field testing programme FIELD 0

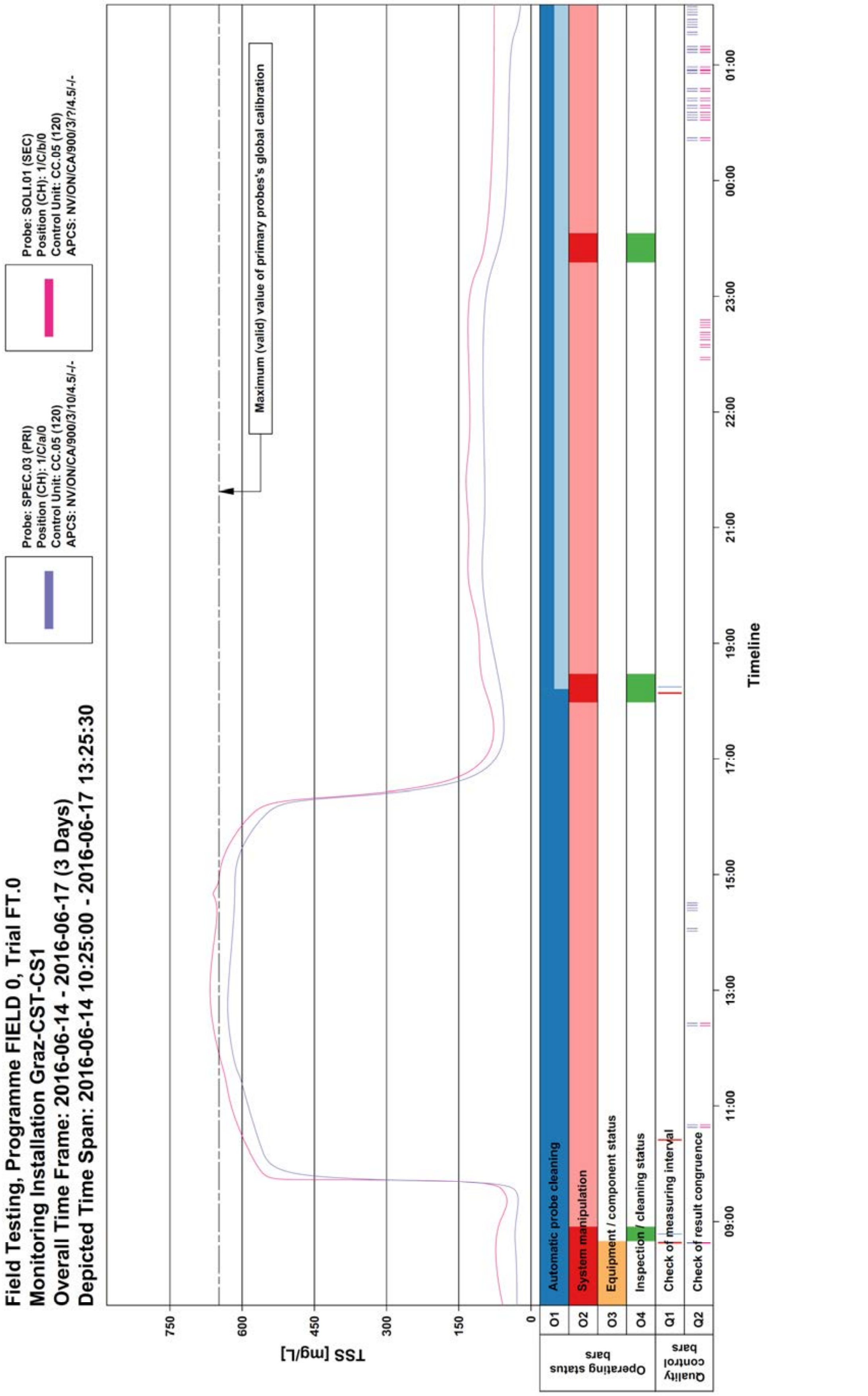
Visualisation for testing programmes FIELD 0 and FIELD 1 differs from the visualisation concept of the laboratory experiments with the exception of operating status bar O2, representing manipulation of the monitoring system. Additionally, the visualisation concept for station Graz-CST-CS1 (FIELD 0), differs slightly from the approach at station Graz-WWTP-CSO (FIELD 1). These differences are owed to the varying mounting types and equipment configurations of the two monitoring stations.

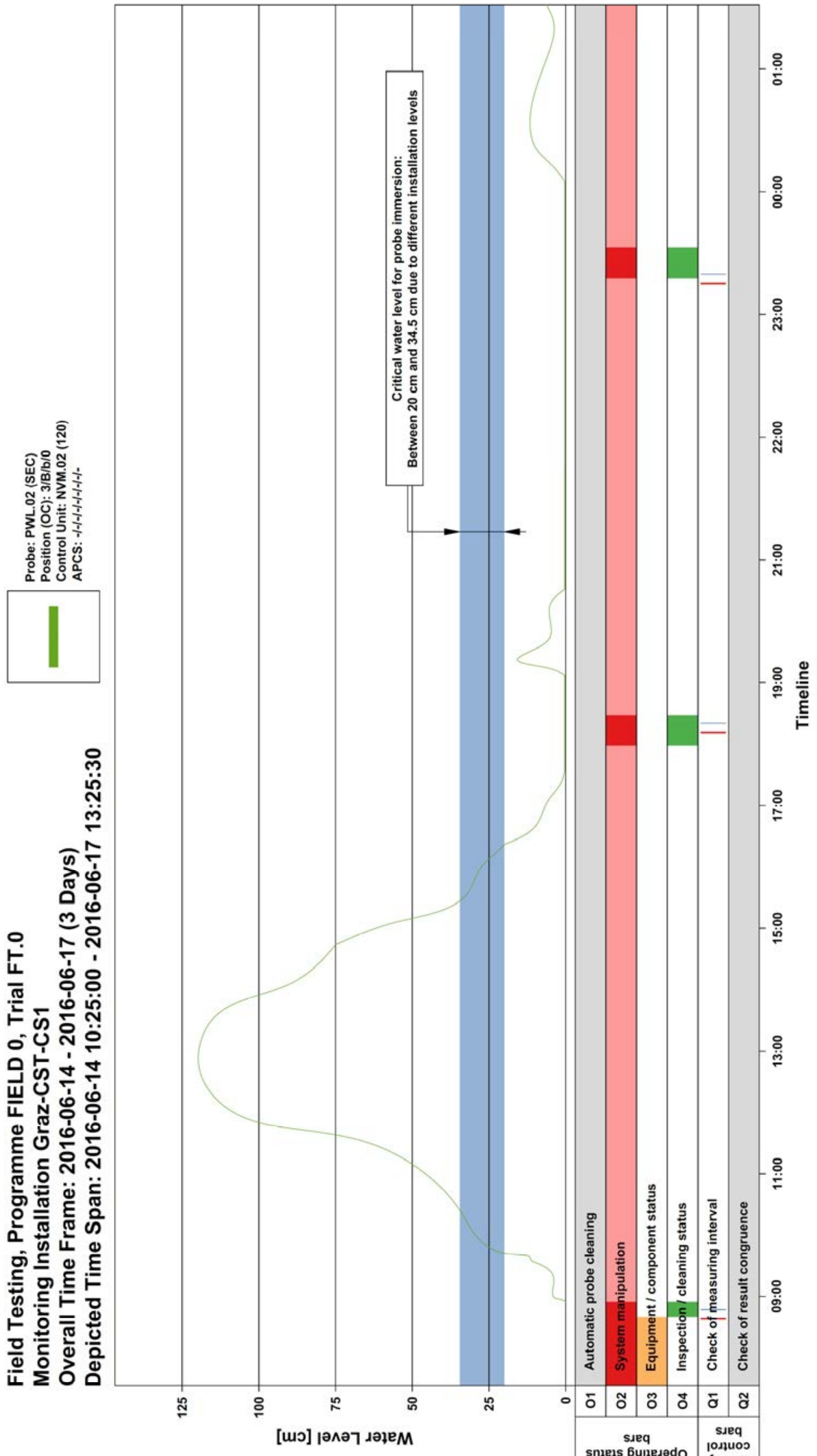
A.2.3.1 Colour scheme for operating status bars and quality control bars

Colour Scheme for Operating Status Bars and Quality Control Bars for Field Testing Programme FIELD 0

Status Bar		Significance	Colour(s)	Significance
Operating Status	O1	Automatic Probe Cleaning	dark blue	Automatic probe cleaning of all probes in the plot is activated
			light blue	Automatic probe cleaning of all probes in the plot is deactivated
			dark blue / light blue	Automatic probe cleaning of at least one probe in the plot is activated
			grey	No automatic probe cleaning data available
	O2	System Manipulation	red	Manipulation of the system
			light red	No manipulation of the system
			grey	No system manipulation data available
	O3	Equipment/ Component Status	white	No installation, replacements, service or repairs
			orange	Equipment installation
			blue	Replacement of wear parts, components, etc.
			light green	Equipment service (e.g. discharge of maintenance unit)
			salmon	Repair works (on probes and mounting systems)
	Q4	Inspection/ Cleaning Status	white	No inspection or cleaning of a probe or the installation
			green	Manual probe cleaning, intensive cleaning standard
			blue	Visual inspection
			yellow	Removal of entangled material
Quality Control	Q1	Check of Measuring Interval	white	Measuring interval meets target interval
			blue	Measuring interval over target interval
			red	Measuring interval under target interval
	Q2	Check of Result Congruence	white	Consecutive measurements deviating
			multiple colours	Consecutive measurements identical, colour matches time series of respective probe

A.2.3.2 Example figures




Field Testing, Programme FIELD 0, Trial FT.0
Monitoring Installation Graz-CST-CS1
Overall Time Frame: 2016-06-14 - 2016-06-17 (3 Days)
Depicted Time Span: 2016-06-14 10:25:00 - 2016-06-17 13:25:30
Probe: PWL.02 (SEC)
Position (OC): 3/B/b/0
Control Unit: NVM.02 (120)
APCS: -/-/-/-/-/-/-
Critical water level for probe immersion:
Between 20 cm and 34.5 cm due to different installation levels
Water Level [cm]
125
100
75
50
25
0
Operating status bars
O1
Automatic probe cleaning
O2
System manipulation
O3
Equipment / component status
O4
Inspection / cleaning status
Quality control bars
Q1
Check of measuring interval
Q2
Check of result congruence
09:00
11:00
13:00
15:00
17:00
19:00
21:00
22:00
23:00
00:00
01:00
Timeline

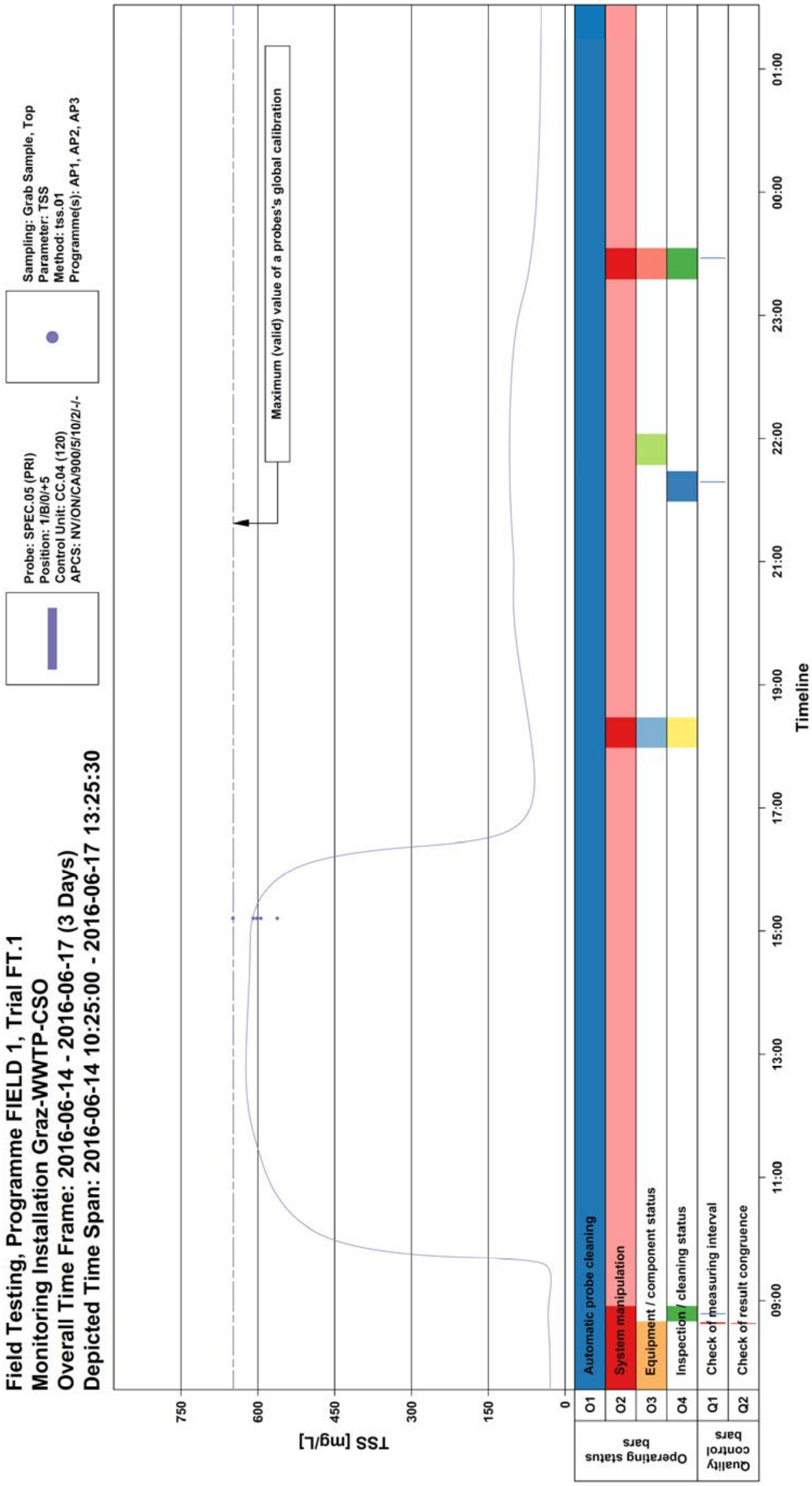
A.2.4 Visualisation concept for field testing programme FIELD 1

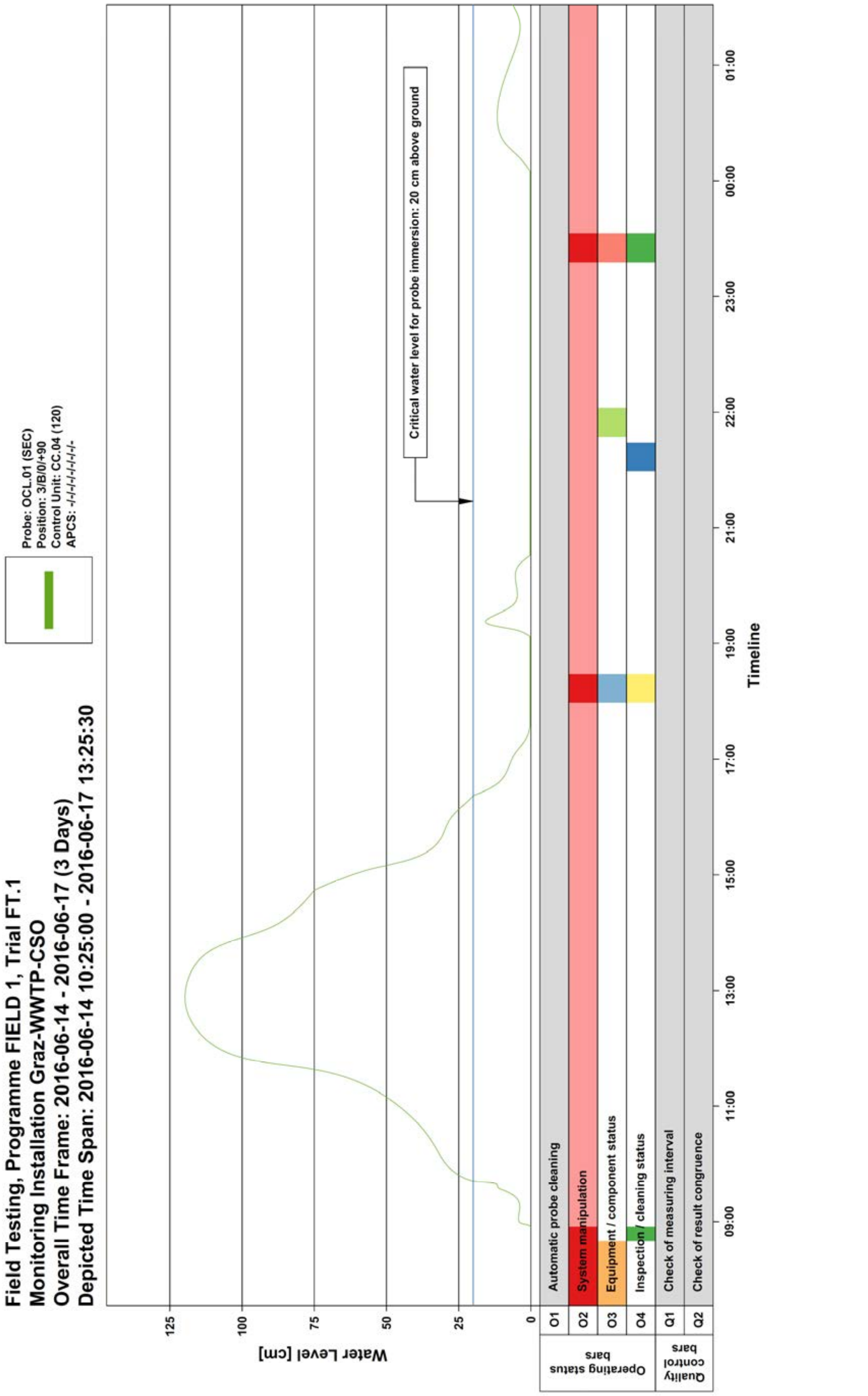
A.2.4.1 Colour scheme for operating status bars and quality control bars

Colour Scheme for Operating Status Bars and Quality Control Bars for Field Testing Programme FIELD 1

Status Bar		Significance	Colour	Significance
Operating Status	O1	Automatic Probe Cleaning		Automatic probe cleaning activated
				Automatic probe cleaning deactivated
				No automatic probe cleaning data available
	O2	System Manipulation		Manipulation of the system
				No manipulation of the system
				No system manipulation data available
	O3	Equipment/ Component Status		No installation, replacements, service or repairs
				Equipment installation
				Replacement of wear parts, components, etc.
				Equipment service (e.g. discharge of maintenance unit)
				Repair works (on probes and mounting systems)
	Q4	Inspection/ Cleaning Status		No inspection or cleaning of a probe or the installation
				Manual probe cleaning, intensive cleaning standard
				Visual inspection
				Removal of entangled material
Quality Control	Q1	Check of Measuring Interval		Measuring interval meets target interval
				Measuring interval over target interval
				Measuring interval under target interval
	Q2	Check of Result Congruence		Consecutive measurements deviating
				Consecutive measurements identical

A.2.4.2 Example figures




Field Testing, Programme FIELD 1, Trial FT.1
Monitoring Installation Graz-WWTP-CSO
Overall Time Frame: 2016-06-14 - 2016-06-17 (3 Days)
Depicted Time Span: 2016-06-14 10:25:00 - 2016-06-17 13:25:30
Probe: OCL.01 (SEC)
Position: 3/B/0/+90
Control Unit: CC.04 (120)
APCS: -/-/-/-/-/-/-
Critical water level for probe immersion: 20 cm above ground
Water Level [cm]
125
100
75
50
25
0
Operating status bars
O1
O2
O3
O4
Quality control bars
Q1
Q2
Automatic probe cleaning
System manipulation
Equipment / component status
Inspection / cleaning status
Check of measuring interval
Check of result congruence
09:00
11:00
13:00
15:00
17:00
19:00
21:00
22:00
23:00
00:00
01:00
Timeline

A.3 Operational data and equipment configuration

Operational data, metadata, information on laboratory sampling and chemical analyses, as well as sensor placement and equipment settings are combined in this section for all laboratory and field trials.

For each trial programme, this information is presented in the following order:

- An operational table of the laboratory reactor or monitoring site in the field, representing major operational phases and states,
- an equipment configuration table for the monitoring station, containing operational settings and probe management data for individual trials, and
- a series of figures and drawings, illustrating probe and sensor placement, combined with drawings highlighting the connections and interdependencies between the used monitoring equipment.

While these tabular and graphic representations were used as tools to interpret the data, see Appendix C for complete time series plots and Appendix B for the raw and processed data, including the *R*-scripts used in generating this output.

A.3.1 Operational and equipment data for laboratory experiments of LAB 1 and LAB 2

A.3.1.1 Reactor data for laboratory trials of LAB 1 and LAB 2

Reactor Configuration for Laboratory Trial Programmes LAB 1 (2015) and LAB 2 (2016)																											
Trial Data					Duration				Environment and Sampling						Agitation Status					Operational Stability				Equipment			
Trial Identification	Reactor Identification	Reactor Identification	Reactor Generation	Equipment Configuration	Days	Hours	Minutes	Seconds	Grab Sample Identification	Medium	Dilution Ration [WW:TW]	Laboratory Sample Identification [+ Reactor Identification]	Analytics Programme	Laboratory Sample Volume [mL]	Agitation Status	Agitation System	Agitation Operation Mode	Reactor Aeration Pressure [bar]	Magnetic Stirrer Setting	Submersion or Immersion	Special operational Conditions	Environmental Stability	Manipulation of Setup	Reactors Operated	Primary Probes	Auto. Cleaned Primary Probes	Secondary Probes
1.1	02 d 00 h 00 m 00 s	L	1	1	00	00	01	00	1.1-1	CWS	1:0	1.1-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
					00	00	09	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	19	47	00	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	30	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
				1/2	00	00	01	00	1.1-1	CWS	1:0	1.1-1-2	AP2	400	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	00	29	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	00	30	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	23	29	30	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	17	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	01	00	1.1-1	CWS	1:0	1.1-1-3	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	42	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	00	30	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	02	32	30	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
		R	1	1	00	00	01	00	1.1-1	CWS	1:0	1.1-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
					00	00	09	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	19	47	00	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	30	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
				1/2	00	00	01	00	1.1-1	CWS	1:0	1.1-1-2	AP2	400	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	00	29	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	00	30	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	23	29	30	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	17	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	01	00	1.1-1	CWS	1:0	1.1-1-3	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	42	00	1.1-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	00	30	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	02	32	30	1.1-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
1.2	03 d 00 h 00 m 00 s	L	1	1	00	00	01	00	1.2-1	CWS	1:0	1.2-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	14	00	1.2-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	22	27	00	1.2-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	33	00	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.2-1	CWS	1:0	1.2-1-2	AP2	400	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	28	45	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
				1/2	00	00	00	15	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
				2	00	22	57	00	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	01	02	45	-	AIR	-	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	22	57	00	1.2-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	33	00	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.2-1	CWS	1:0	1.2-1-3	AP1	1500	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	15	00	1.2-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
		R	1	1	00	00	01	00	1.2-1	CWS	1:0	1.2-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	14	00	1.2-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	22	27	00	1.2-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	33	00	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	30	1.2-1	CWS	1:0	1.2-1-2	AP2	400	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
				1/2	00	00	28	30	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
					00	22	56	30	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	01	02	45	-	AIR	-	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	22	57	00	1.2-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	33	00	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0

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1.2		R	1	3	00	00	01	00	1.2-1	CWS	1:0	1.2-1-3	AP1	1500	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.2-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	15	00	1.2-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
1.3	03 d 00 h 00 m 00 s	L	1	1	00	00	01	00	1.3-1	CWS	1:0	1.3-1-1	AP1	1500	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
					00	03	39	00	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	19	27	00	1.3-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	00	33	00	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	00	01	00	1.3-1	CWS	1:0	1.3-1-2	AP2	400	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
					00	00	29	45	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
				1/2	00	00	00	15	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	22	56	00	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	01	02	45	-	AIR	-	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
				3/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
				3	00	22	57	00	1.3-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	00	33	00	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	00	01	00	1.3-1	CWS	1:0	1.3-1-3	AP1	1500	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
					00	00	18	30	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	00	00	30	1.3-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
		R	1	1	00	00	01	00	1.3-1	CWS	1:0	1.3-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
					00	03	39	00	1.3-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	19	27	00	1.3-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	33	00	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
				1/2	00	00	31	00	1.3-1	CWS	1:0	1.3-1-2	AP2	400	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	22	56	00	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	01	02	45	-	AIR	-	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
				3	00	22	57	00	1.3-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	00	33	00	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	00	01	00	1.3-1	CWS	1:0	1.3-1-3	AP1	1500	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
					00	00	18	30	1.3-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
					00	00	00	30	1.3-1	CWS	1:0	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	0	0
1.4	10 d 00 h 00 m 00 s	L	1	1	00	00	01	00	1.4-1	CWS	1:0	1.4-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.4-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					01	20	31	00	1.4-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.4-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.4-1	CWS	1:0	1.4-1-2	AP1	1500	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	28	45	1.4-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
				1/2	00	00	00	15	1.4-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
				2	06	00	58	45	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	01	00	1.4-2	CWS	1:0	1.4-2-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.4-2	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					01	21	30	00	1.4-2	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.4-2	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.4-2	CWS	1:0	1.4-2-2	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.4-2	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	02	00	00	1.4-2	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
		R	1	1	00	00	01	00	1.4-1	CWS	1:0	1.4-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.4-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					01	20	31	00	1.4-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.4-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
					00	00	02	30	1.4-1	CWS	1:0	1.4-1-2	AP1	1500	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
				1/2	00	00	27	30	1.4-1	CWS	1:0	-	-	-	ON	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	MAN	2	1	0	0
					06	00	58	15	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	OFF	MS	TC	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	01	00	1.4-2	CWS	1:0	1.4-2-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.4-2	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					01	21	30	00	1.4-2	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.4-2	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.4-2	CWS	1:0	1.4-2-2	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.4-2	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	02	00	00	1.4-2	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
1.5		L	1	1	00	00	01	00	1.5-1	CWS	1:0	1.5-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	22	15	00	1.5-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0

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1.5	03 d 00 h 00 m 00 s	L	1	1	00	00	01	00	1.5-1	CWS	1:0	1.5-1-2	AP2	1200	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	28	45	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				1/2	00	00	00	15	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				2	00	23	00	00	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	29	45	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	30	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	23	00	00	1.5-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	31	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.5-1	CWS	1:0	1.5-1-3	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	28	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	15	00	1.5-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
		R	1	1	00	00	01	00	1.5-1	CWS	1:0	1.5-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	22	15	00	1.5-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	02	30	1.5-1	CWS	1:0	1.5-1-2	AP2	1200	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				1/2	00	00	27	30	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
					00	22	59	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	29	45	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	30	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	23	00	00	1.5-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	31	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.5-1	CWS	1:0	1.5-1-3	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	28	00	1.5-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	15	00	1.5-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
1.6	02 d 05 h 51 m 00 s	L	1	1	00	00	01	00	1.6-1	CWS	1:0	1.6-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	22	45	00	1.6-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.6-1	CWS	1:0	1.6-1-2	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	28	45	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				1/2	00	00	00	15	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				2	00	03	30	00	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	29	45	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	30	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	18	30	00	1.6-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.6-1	CWS	1:0	1.6-1-3	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	28	45	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				3/4	00	00	00	15	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				4	00	03	30	00	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	29	45	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				4/5	00	00	00	15	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				5	00	00	30	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	01	06	00	1.6-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
		R	1	1	00	00	01	00	1.6-1	CWS	1:0	1.6-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	22	45	00	1.6-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	02	30	1.6-1	CWS	1:0	1.6-1-2	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	27	30	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				1/2	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	03	29	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	29	45	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	30	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	18	30	00	1.6-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	30	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	03	30	1.6-1	CWS	1:0	1.6-1-3	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	26	30	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				3/4	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				4	00	03	29	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	29	45	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0

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1.6		R	1	4/5	00	00	00	15	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				5	00	00	30	00	1.6-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	01	06	00	1.6-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
1.7	02 d 03 h 30 m 00 s	L	1	1	00	00	01	00	1.7-1	CWS	1:0	1.7-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
					00	00	29	00	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	22	00	00	1.7-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	32	00	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	28	00	1.7-1	CWS	1:0	1.7-1-2	AP1	1000	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				1/2	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	22	59	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	14	45	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	15	00	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	00	1.7-1	CWS	1:0	1.7-1-3	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	04	00	00	1.7-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
		R	1	1	00	00	01	00	1.7-1	CWS	1:0	1.7-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
					00	00	29	00	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	22	00	00	1.7-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	32	00	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	28	00	1.7-1	CWS	1:0	1.7-1-2	AP1	1000	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				1/2	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				2	00	22	59	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	14	45	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	00	00	30	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	14	30	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	00	01	00	1.7-1	CWS	1:0	1.7-1-3	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
					00	00	29	00	1.7-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
					00	04	00	00	1.7-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	0	0
1.8	10 d 00 h 00 m 00 s	L	1	1	00	00	01	00	1.8-1	CWS	1:0	1.8-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.8-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	20	15	00	1.8-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	31	00	1.8-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	01	30	1.8-1	CWS	1:0	1.8-1-2	AP1	1000	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	27	30	1.8-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				1/2	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	SOC	STB	MAN	2	1	0	0
				2a 2b	01	23	59	45	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	SOC	STB	-	2	1	0	0
					00	00	00	15	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	SOC	STB	MAN	2	1	0	0
					05	07	14	15	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	01	00	00	1.8-2	CWS	2:1	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					01	15	30	00	1.8-2	CWS	2:1	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	01	00	00	1.8-2	CWS	2:1	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	01	30	00	1.8-2	CWS	2:1	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
		R	1	1	00	00	01	00	1.8-1	CWS	1:0	1.8-1-1	AP1	1500	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	29	00	1.8-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	20	15	00	1.8-1	CWS	1:0	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	31	00	1.8-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	00	06	30	1.8-1	CWS	1:0	1.8-1-2	AP1	1000	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
					00	00	22	30	1.8-1	CWS	1:0	-	-	-	ON	MS	MO	-	M	IMM	-	STB	MAN	2	1	0	0
				1/2	00	00	00	30	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	SOC	STB	MAN	2	1	0	0
				2a 2b	01	23	59	45	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	SOC	STB	-	2	1	1	0
					00	00	00	15	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	SOC	STB	MAN	2	1	1	0
					05	07	14	15	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
				2/3	00	00	00	15	-	AIR	-	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	MAN	2	1	1	0
				3	00	01	00	00	1.8-2	CWS	2:1	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					01	15	30	00	1.8-2	CWS	2:1	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	01	00	00	1.8-2	CWS	2:1	-	-	-	ON	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
					00	01	30	00	1.8-2	CWS	2:1	-	-	-	OFF	MS	MO	-	M	IMM	-	STB	-	2	1	1	0
2.1	03 d 02 h 00 m 30 s	1	2	-	00	00	39	45	2.1-1	CWS	1:0	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	MAN	2	0	0	0
					00	00	04	30	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0
					00	00	01	30	2.1-1	CWS	1:0	2.1-1-1	AP3	900	ON	RA	MO	2.6	-	SUB	-	STB	MAN	2	0	0	0
					00	00	04	00	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0
					00	23	40	00	2.1-1	CWS	1:0	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0
					00	00	20	00	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0
					00	23	50	00	2.1-1	CWS	1:0	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0

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2.1	03 d 02 h 00 m 30 s	1	2	-	00	00	10	00	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0
					00	23	40	00	2.1-1	CWS	1:0	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0
					00	00	20	15	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0
					00	00	06	15	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	DIS	-	2	0	0	0
					00	01	53	45	-	AIR	-	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	-	2	0	0	0
					00	00	10	30	-	AIR	-	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	MAN	2	0	0	0
		2	2	1	00	00	39	45	2.1-1	CWS	1:0	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	MAN	2	3	8	0
					00	00	04	30	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	3
					00	00	01	30	2.1-1	CWS	1:0	2.1-1-1	AP3	900	ON	RA	MO	2.6	-	SUB	-	STB	MAN	2	3	8	3
					00	00	04	00	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	3
					00	23	40	00	2.1-1	CWS	1:0	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	3
				1/2	00	00	20	00	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	3
				2	00	23	50	00	2.1-1	CWS	1:0	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	3
				2/3	00	00	10	00	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	3
				3	00	23	40	00	2.1-1	CWS	1:0	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	3
					00	00	20	15	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	0
					00	00	06	15	2.1-1	CWS	1:0	-	-	-	ON	RA	MO	2.6	-	SUB	-	DIS	-	2	3	8	0
					00	01	53	45	-	AIR	-	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	-	2	3	8	0
					00	00	10	30	-	AIR	-	-	-	-	OFF	RA	MO	2.6	-	SUB	-	STB	MAN	2	3	8	0
2.2	04 d 07 h 19 m 15 s	1	2	1	00	00	02	30	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	01	30	2.2-1	CWS	1:0	2.2-1-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					00	00	02	00	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	23	43	00	2.2-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
				1/2	00	00	20	00	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
				2	00	23	40	00	2.2-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
				2/3	00	00	20	00	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	0
				3	02	05	40	00	2.2-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	0
					00	00	09	45	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	0
					00	00	05	00	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	1	7	0
					00	00	00	15	-	AIR	-	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	1	7	0
					00	01	15	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	0
		2	2	1	00	00	02	30	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	01	30	2.2-1	CWS	1:0	2.2-1-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					00	00	02	00	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	23	43	00	2.2-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
				1/2	00	00	20	00	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
				2	00	23	40	00	2.2-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
				2/3	00	00	20	00	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	0
				3	02	05	38	00	2.2-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	0
					00	00	11	45	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	0
					00	00	05	45	2.2-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	2	4	0
					00	01	14	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	0
2.3	15 d 03 h 30 m 00 s	1	2	1	00	01	36	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	02	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	1	7	1
					00	00	50	45	2.3-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	04	00	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	01	30	2.3-1	CWS	1:0	2.3-1-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					00	00	04	30	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	23	50	00	2.3-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	10	00	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	01	30	2.3-1	CWS	1:0	2.3-1-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					00	00	04	00	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	04	00	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	1	7	1
					00	00	02	45	-	AIR	-	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	1	7	1
					00	01	17	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	12	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					05	20	08	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
				1/2	00	00	27	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
				2	00	00	03	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	1	7	1
					00	00	06	30	2.3-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	03	00	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	01	30	2.3-2	CWS	1:0	2.3-2-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					00	00	05	00	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	23	40	00	2.3-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	28	30	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	01	00	2.3-2	CWS	1:0	2.3-2-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					00	00	00	30	2.3-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1

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2.3	15 d 03 h 30 m 00 s	1	2		00	23	30	00	2.3-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	10	30	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	01	30	2.3-2	CWS	1:0	2.3-2-3	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					00	00	10	45	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	03	45	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	1	7	1
					00	00	02	15	-	AIR	-	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	1	7	1
					00	00	33	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	09	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					04	22	00	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
				2/3	00	00	41	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
				3	00	02	03	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	02	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	1	7	1
					00	00	05	15	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	05	00	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	01	30	2.3-3	CWS	1:0	2.3-3-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					00	00	03	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	23	40	00	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	19	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	01	30	2.3-3	CWS	1:0	2.3-3-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	1	7	1
					00	00	08	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	1
					00	00	10	15	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	1	7	0
		2	2	1	00	01	36	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	02	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	3	4	3
					00	00	50	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	04	00	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	01	30	2.3-1	CWS	1:0	2.3-1-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	3
					00	00	04	30	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	23	49	00	2.3-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	11	00	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	01	30	2.3-1	CWS	1:0	2.3-1-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	3
					00	00	04	00	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	06	15	2.3-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	3	4	3
					00	00	00	30	-	AIR	-	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	3	4	3
					00	00	18	30	-	AIR	-	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	01	15	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
				1/2	00	00	10	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	3
				2	05	20	21	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	03	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	3	4	3
					00	00	06	30	2.3-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	03	00	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	01	30	2.3-2	CWS	1:0	2.3-2-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	3
					00	00	04	30	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	23	40	30	2.3-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	28	30	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	01	00	2.3-2	CWS	1:0	2.3-2-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	3
					00	00	00	30	2.3-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	3
					00	23	30	00	2.3-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	10	30	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	01	30	2.3-2	CWS	1:0	2.3-2-3	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	3
					00	00	09	45	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	04	45	2.3-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	3	4	3
					00	00	02	15	-	AIR	-	-	-	-	ON	RA	MO	2.0	-	SUB	-	DIS	-	2	3	4	3
					00	00	08	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	3
					00	00	18	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	3
					04	22	29	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1
				2/3	00	00	29	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	1
				3	00	02	02	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1
					00	00	03	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	3	4	1
					00	00	05	15	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1
					00	00	05	00	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1
					00	00	01	30	2.3-3	CWS	1:0	2.3-3-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	1
					00	00	03	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1
					00	23	41	00	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1
					00	00	18	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1
					00	00	01	30	2.3-3	CWS	1:0	2.3-3-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	3	4	1
					00	00	04	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1
					00	00	14	15	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	3	4	1

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2.4	18 d 00 h 55 m 00 s	1	2	1	00	00	00	15	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	01	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	01	30	2.3-3	CWS	1:0	2.3-3-3	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					00	00	08	00	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	23	40	30	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	17	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	01	30	2.3-3	CWS	1:0	2.3-3-4	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					00	00	01	00	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	03	45	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	04	45	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	7	0
					00	00	02	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	7	0
					00	00	05	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	08	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					03	15	00	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
				1/2	00	00	34	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
				2	00	01	46	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	03	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	2	7	0
					00	00	00	45	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	09	00	2.4-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	01	30	2.4-1	CWS	1:0	2.4-1-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					00	00	09	00	2.4-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	00	45	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	03	00	00	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	7	0
					00	01	22	45	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	MAN	2	2	7	0
					00	00	01	00	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	7	0
					00	00	01	00	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	2	7	0
					00	19	34	00	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	09	30	2.4-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	01	30	2.4-1	CWS	1:0	2.4-1-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					00	00	08	30	2.4-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	29	45	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	04	45	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	7	0
					00	00	01	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	7	0
					00	00	18	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	08	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					08	19	45	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
				2/3	00	00	47	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
				3	00	03	00	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	02	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	2	7	0
					00	00	00	45	2.4-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	06	30	2.4-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	01	30	2.4-2	CWS	1:0	2.4-2-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					00	00	07	00	2.4-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	22	34	00	2.4-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	17	30	2.4-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	01	30	2.4-2	CWS	1:0	2.4-2-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					00	00	00	45	2.4-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	32	30	2.4-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	02	45	2.4-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	7	0
					00	00	02	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	7	0
					00	01	44	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
					00	00	13	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	7	0
					02	03	55	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	7	0
		2	2	1	00	00	00	15	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	01	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	01	30	2.3-3	CWS	1:0	2.3-3-3	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					00	00	08	00	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	23	40	00	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	18	00	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	01	30	2.3-3	CWS	1:0	2.3-3-4	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					00	00	00	30	2.3-3	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	03	15	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	04	45	2.3-3	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	4	2
					00	00	03	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	4	2
					00	00	13	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	06	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					03	14	57	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2

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2.4	18 d 00 h 55 m 00 s	2	2	1/2	00	00	31	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
				2	00	01	46	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	03	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	2	4	2
					00	00	00	45	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	09	00	2.4-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	01	30	2.4-1	CWS	1:0	2.4-1-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					00	00	09	30	2.4-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	23	59	00	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	09	30	2.4-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	01	30	2.4-1	CWS	1:0	2.4-1-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					00	00	08	30	2.4-1	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	29	45	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	04	45	2.4-1	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	4	2
					00	00	01	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	4	2
					00	00	01	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	07	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					01	23	34	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	23	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					06	20	00	30	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
				2/3	00	00	51	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
				3	00	03	00	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	02	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	CHG	MAN	2	2	4	2
					00	00	00	45	2.4-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	06	30	2.4-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	01	30	2.4-2	CWS	1:0	2.4-2-1	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					00	00	06	30	2.4-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	22	34	30	2.4-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	17	30	2.4-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	01	30	2.4-2	CWS	1:0	2.4-2-2	AP3	900	ON	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					00	00	00	45	2.4-2	CWS	1:0	-	-	-	ON	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	32	30	2.4-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	02	15	2.4-2	CWS	1:0	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	4	2
					00	00	02	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	DIS	-	2	2	4	2
					00	01	31	45	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2
					00	00	12	00	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	MAN	2	2	4	2
					02	04	09	15	-	AIR	-	-	-	-	OFF	RA	MO	2.0	-	SUB	-	STB	-	2	2	4	2

end of table

A.3.1.2 Equipment placement and configuration for laboratory trials of LAB 1 and LAB 2

Equipment Configurations and Sensor Placement for Laboratory Trial Programmes LAB 1 (2015) and LAB 2 (2016)																													
Equipment Positions and Connections, Basic Settings										Equipment Configuration 1										Equipment Configuration 2									
											Automatic Probe Cleaning Settings (APCS)										Automatic Probe Cleaning Settings (APCS)								
Trial ID	Reactor ID	Level	Main Position	Auxiliary Position	Probe Inclination [°]	Probe ID	Probe Category	Control Unit Identification	Logger Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]
1.1	L	0	B	-	0	SPEC.01	PRI	CS.01	60	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	ON	CA	900	3	20	2	-	-
	R	0	B	-	0	SPEC.02	PRI	CS.02	60	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	ON	CA	900	3	20	2	-	-
1.2	L	0	B	-	0	SPEC.01	PRI	CS.01	60	IC	NV	ON	CA	900	3	20	2	-	-	NC	NV	OFF	-	-	-	-	-	-	-
	R	0	B	-	0	SPEC.02	PRI	CS.02	60	IC	NV	ON	CA	900	2	20	2	-	-	NC	NV	ON	CA	900	2	20	2	-	-
1.3	L	0	B	-	0	SPEC.01	PRI	CS.01	60	IC	NV	OFF	-	-	-	-	-	-	-	IC	NV	OFF	-	-	-	-	-	-	-
	R	0	B	-	0	SPEC.02	PRI	CS.02	60	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	OFF	-	-	-	-	-	-	-
1.4	L	0	B	-	0	SPEC.01	PRI	CS.01	60	IC	NV	ON	CA	900	3	20	2	-	-	NC	NV	OFF	-	-	-	-	-	-	-
	R	0	B	-	0	SPEC.02	PRI	CS.02	60	IC	NV	ON	CA	900	3	20	2	-	-	NC	NV	ON	CA	900	3	20	2	-	-
1.5	L	0	B	-	0	SPEC.01	PRI	CS.01	60	IC	NV	ON	CA	300	3	20	2	-	-	NC	NV	OFF	-	-	-	-		-	-
	R	0	B	-	0	SPEC.02	PRI	CS.02	60	IC	NV	ON	CA	300	3	20	2	-	-	NC	NV	ON	CA	300	3	20	2	-	-
1.6	L	0	B	-	0	SPEC.01	PRI	CS.01	60	IC	NV	ON	CA	300	3	20	2	-	-	NC	NV	OFF	-	-	-	-	-	-	-
	R	0	B	-	0	SPEC.02	PRI	CS.02	60	IC	NV	ON	CA	300	3	20	2	-	-	NC	NV	ON	CA	300	3	20	2	-	-
1.7	L	0	B	-	0	SPEC.01	PRI	CS.01	60	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	ON	CA	900	3	20	4	-	-
	R	0	B	-	0	SPEC.02	PRI	CS.02	60	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	ON	TW	900	3	20	2	-	-
1.8	L	0	B	-	0	SPEC.01	PRI	CS.01	60	IC	NV	ON	CA	900	3	20	2	-	-	NC	NV	OFF	-	-	-	-	-	-	-
	R	0	B	-	0	SPEC.02	PRI	CS.02	60	IC	NV	ON	CA	900	3	20	2	-	-	NC	NV	OFF	-	-	-	-	-	-	-
2.1	2	3	A	c	0	LDO.02	SEC	HQ40.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		2	A	c	0	LDO.01	SEC	HQ40.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	A	-	0	ISCAN.01	PRI	CC.01	60	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	ON	CA	300	3	5	2.6	-	-
		1	A	c	+160	PH.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	B	-	0	SPEC.02	PRI	CS.01	30	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	ON	CA	300	3	5	2.6	-	-
		1	B	a	-15	FDO.01	SEC	MULTI.01	30	IC	NV	OFF	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	B	b	-15	FDO.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	B	b	0	LDO.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	B	b	+180	PH.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	B	c	-10	EC.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	C	-	0	ISCAN.02	PRI	CC.01	60	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	ON	CA	300	3	5	2.6	-	-
		1	C	a	-15	EC.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
2.2	1	3	A	-	0	ST.01	SEC	SCM.01	5	IC	-	-	-	-	-	-	-	ON	1800	NC	-	-	-	-	-	-	-	-	-
		3	C	-	0	LDO.01	SEC	HQ40.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		2	A	-	0	ST.02	SEC	SCM.01	5	IC	-	-	-	-	-	-	-	ON	1800	NC	-	-	-	-	-	-	-	-	-
		1	A	-	0	ST.03	SEC	SCM.01	5	IC	-	-	-	-	-	-	-	ON	1800	NC	-	-	-	-	-	-	-	-	-
		1	B	-	0	SPEC.03	PRI	CS.02	30	IC	NV	ON	CA	900	5	10	2	-	-	NC	NV	ON	CA	900	3	10	2	-	-
		1	C	a	-5	EC.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	C	b	-5	PH.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	C	c	-5	FDO.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
	2	3	C	-	0	LDO.02	SEC	HQ40.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	A	-	0	SPEC.04	PRI	CC.02	90	IC	CV	ON	CA	300	3	10	2	-	-	NC	CV	ON	CA	300	5	10	2	-	-
		1	B	-	0	SPEC.02	PRI	CC.02	90	IC	CV	ON	CA	300	3	10	2	-	-	NC	CV	ON	CA	300	5	10	2	-	-
		1	C	a	+5	PH.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	C	b	+5	FDO.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-
		1	C	c	+5	EC.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-

			Equipment Configuration 3										Equipment Configuration 4										Equipment Configuration 5									
				Automatic Probe Cleaning Settings (APCS)										Automatic Probe Cleaning Settings (APCS)										Automatic Probe Cleaning Settings (APCS)								
Trial ID	Reactor ID	Probe ID	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]
1.1	L	SPEC.01	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	R	SPEC.02	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2	L	SPEC.01	IC	NV	ON	CA	900	3	20	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	R	SPEC.02	NC	NV	ON	CA	900	2	20	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.3	L	SPEC.01	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	R	SPEC.02	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.4	L	SPEC.01	IC	NV	ON	CA	900	3	20	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	R	SPEC.02	NC	NV	ON	CA	900	3	20	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.5	L	SPEC.01	IC	NV	ON	CA	300	3	20	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	R	SPEC.02	NC	NV	ON	CA	300	3	20	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.6	L	SPEC.01	IC	NV	ON	CA	300	3	20	2	-	-	NC	NV	OFF	-	-	-	-	-	-	-	IC	NV	ON	CA	300	3	20	2	-	-
	R	SPEC.02	NC	NV	ON	CA	300	3	20	2	-	-	NC	NV	ON	CA	300	3	20	2	-	-	NC	NV	ON	CA	300	3	20	2	-	-
1.7	L	SPEC.01	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	R	SPEC.02	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.8	L	SPEC.01	NC	NV	ON	CA	900	3	20	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	R	SPEC.02	NC	NV	ON	CA	900	3	20	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.1	2	LDO.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		LDO.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		ISCAN.01	NC	NV	ON	CA	900	3	5	2.6	-	-	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		PH.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SPEC.02	NC	NV	ON	CA	900	3	5	2.6	-	-	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		FDO.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		FDO.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		LDO.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		PH.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		EC.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		ISCAN.02	NC	NV	ON	CA	900	3	5	2.6	-	-	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		EC.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.2	1	ST.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		LDO.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		ST.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		ST.03	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SPEC.03	NC	NV	ON	CA	3600	3	10	2	-	-	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		EC.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		PH.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		FDO.01	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	LDO.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SPEC.04	NC	CV	OFF	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		SPEC.02	NC	CV	ON	CA	900	5	10	2	-	-	NC	CV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		PH.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		FDO.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		EC.02	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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continued from previous table

Equipment Position and Connections, Basic Settings										Equipment Configuration 1										Equipment Configuration 2										Equipment Configuration 3										Equipment Configuration 4										Equipment Configuration 5									
											Automatic Probe Cleaning Settings (APCS)										Automatic Probe Cleaning Settings (APCS)										Automatic Probe Cleaning Settings (APCS)										Automatic Probe Cleaning Settings (APCS)										Automatic Probe Cleaning Settings (APCS)								
Trial ID	Reactor ID	Level	Main Position	Auxiliary Position	Probe Inclination [°]	Probe ID	Probe Category	Control Unit ID	Logger Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Pressure [bar]	Wiper Status	Wiper Interval [sec]
2.3	**1**	3	A	-	0	ST.01	SEC	SCM.01	5	IC	-	-	-	-	-	-	-	ON	1800	IC	-	-	-	-	-	-	-	ON	1800	IC	-	-	-	-	-	-	-	ON	1800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3	C	-	0	LDO.01	SEC	HQ40.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	A	-	0	ST.02	SEC	SCM.01	5	IC	-	-	-	-	-	-	-	ON	1800	IC	-	-	-	-	-	-	-	ON	1800	IC	-	-	-	-	-	-	-	ON	1800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	A	-	0	ST.03	SEC	SCM.01	5	IC	-	-	-	-	-	-	-	ON	1800	IC	-	-	-	-	-	-	-	ON	1800	IC	-	-	-	-	-	-	-	ON	1800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	B	-	0	SPEC.03	PRI	CS.02	30	IC	NV	ON	CA	900	3	10	2	-	-	IC	NV	ON	CA	900	3	10	2	-	-	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	C	a	-5	EC.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	C	b	-5	PH.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	C	c	-5	FDO.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	3	A	-	0	ISCAN.01	PRI	CC.01	90	IC	NV	ON	CA	900	3	10	2	-	-	IC	NV	OFF	-	-	-	-	-	-	-	NC	NV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		3	C	-	0	LDO.02	SEC	HQ40.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	A	-	0	SPEC.04	PRI	CC.02	90	IC	CV	ON	CA	900	3	10	2	-	-	NC	CV	OFF	-	-	-	-	-	-	-	NC	CV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	B	-	0	SPEC.02	PRI	CC.02	90	IC	CV	ON	CA	900	3	10	2	-	-	NC	CV	ON	CA	900	3	10	2	-	-	NC	CV	ON	CA	900	3	10	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	C	a	+5	PH.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	C	b	+5	FDO.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	C	c	+5	EC.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.4	**1**	3	A	-	0	ST.02	SEC	SCM.01	5	IC	-	-	-	-	-	-	-	ON	300	IC	-	-	-	-	-	-	-	ON	300	IC	-	-	-	-	-	-	-	ON	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	A	-	0	ST.01	SEC	SCM.01	5	IC	-	-	-	-	-	-	-	ON	300	IC	-	-	-	-	-	-	-	ON	300	IC	-	-	-	-	-	-	-	ON	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	B	-	0	LDO.01	SEC	HQ40.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	C	a	-5	EC.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	C	b	-5	PH.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	C	c	-5	FDO.01	SEC	MULTI.01	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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		1	B	-	0	SPEC.03	PRI	CS.02	30	IC	CV	OFF	-	-	-	-	-	-	-	IC	CV	OFF	-	-	-	-	-	-	-	NC	CV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	C	-	0	SPEC.02	PRI	CC.02	90	IC	CV	OFF	-	-	-	-	-	-	-	IC	CV	OFF	-	-	-	-	-	-	-	NC	CV	OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	3	A	-	-5	LDO.02	SEC	HQ40.01	30	IC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	NC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	A	a	+5	PH.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	A	b	+5	FDO.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	A	c	+5	EC.02	SEC	MULTI.02	30	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	IC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	B	-	0	SPEC.04	PRI	CC.02	90	IC	CV	ON	CA	300	5	10	2	-	-	IC	CV	ON	CA	300	5	10	2	-	-	NC	CV	ON	CA	300	5	10	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		1	C	-	0	ISCAN.01	PRI	CC.01	90	IC	NV	ON	CA	300	5	10	2	-	-	IC	NV	ON	CA	300	5	10	2	-	-	NC	NV	ON	CA	300	5	10	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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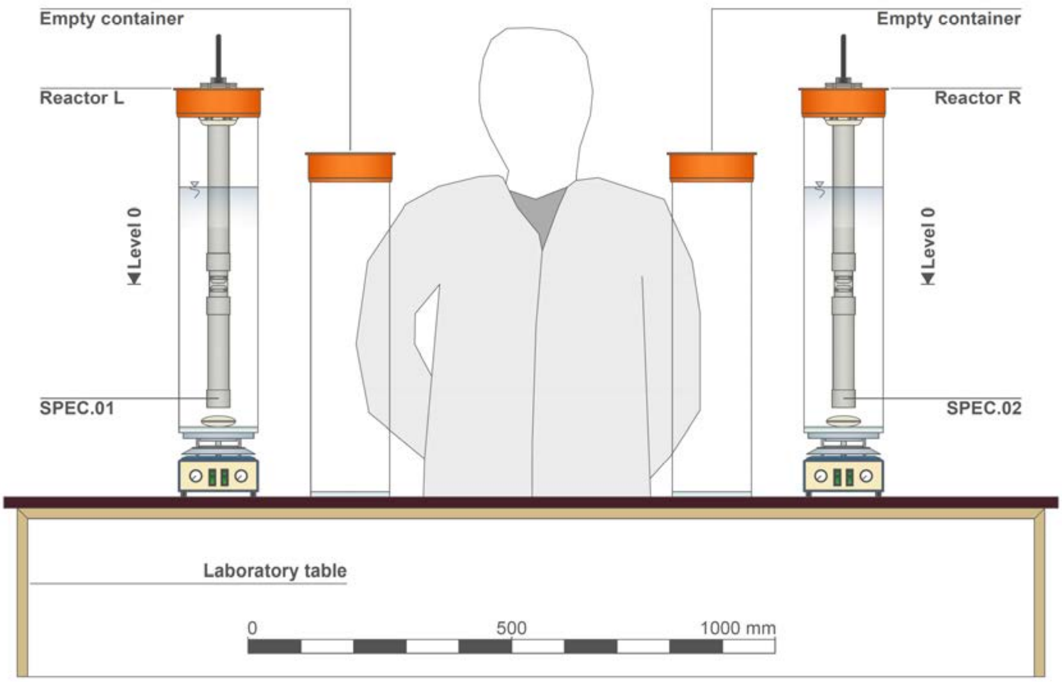
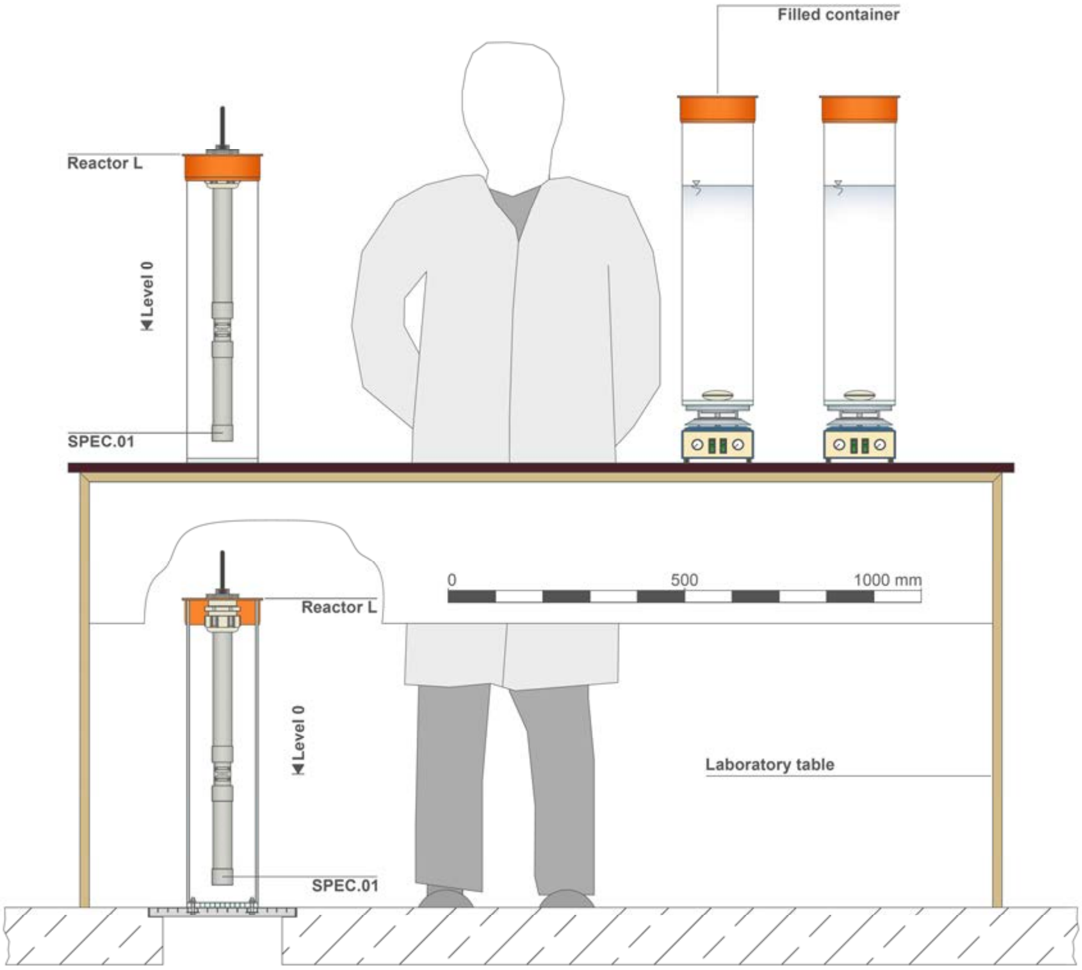
A.3.2 Setup for laboratory trials of LAB 1

While the basic setup of the reactors used during stage one of the laboratory experiments (LAB 1) is depicted in the first figure below, the following figure shows an adapted version of Reactor L, which was used during Trial 1.7, when tap water was tested as a possible alternative medium to compressed air for automatic probe cleaning. While the overall geometry and the mounting system are identical to the basic design of the GEN 1-reactors used during the other trials of LAB 1, the altered version of Reactor L for Trial 1.7 contains borings in the bottom plate and is mounted above a drain to avoid flooding of the laboratory.

A.3.2.1 Setup during immersion periods for all trials of LAB 1



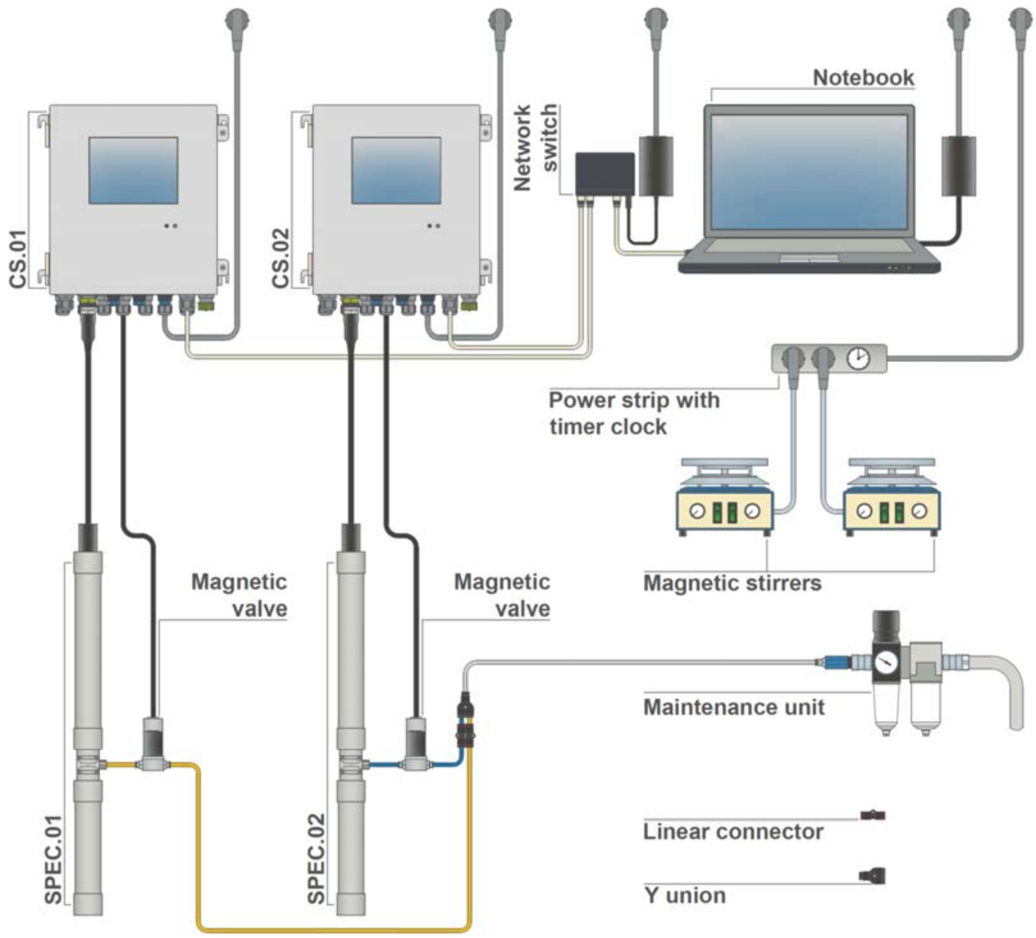
A.3.2.2 Setup during the dry period of Trial 1.7



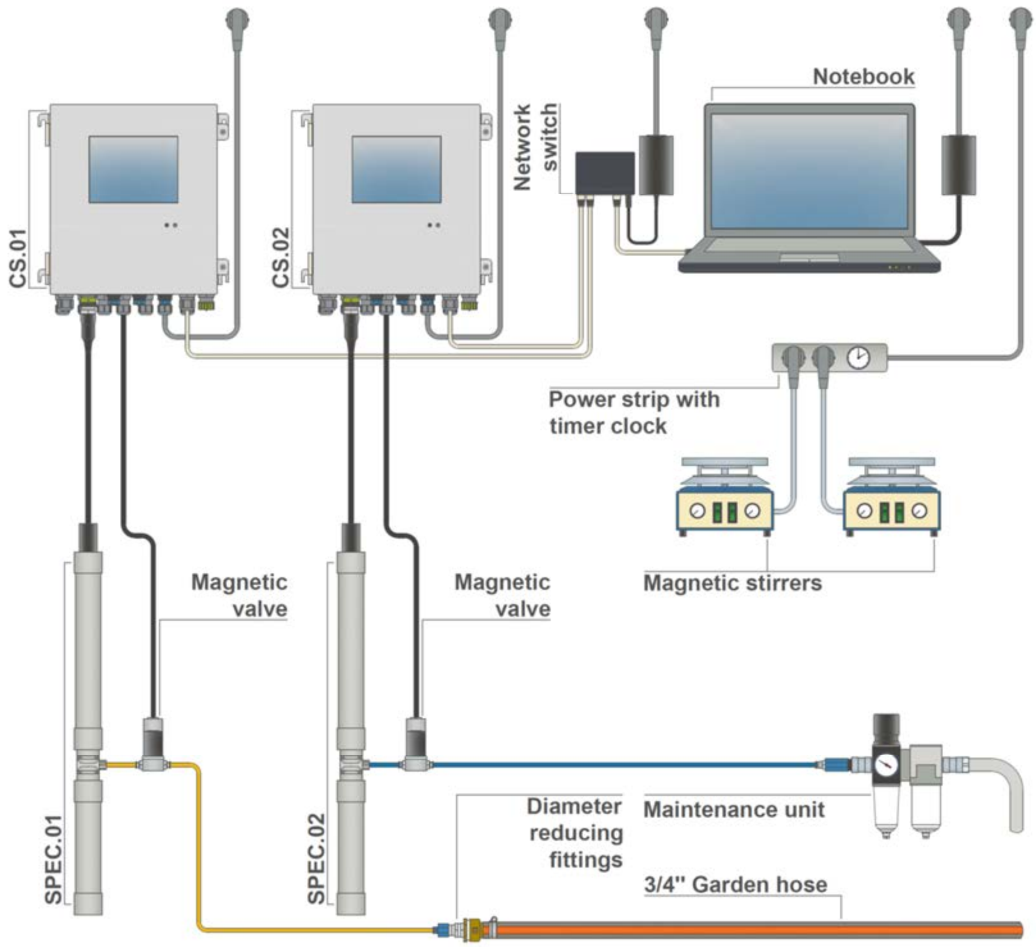
A.3.2.3 Equipment configuration for laboratory trials of LAB 1

During Trial 1.7 the spectrometer probe in Reactor L was automatically cleaned with tap water instead of compressed air, thus a slightly different setup was used. A 3/4-inch garden hose, connected to the building utilities and multiple fittings were combined to enable the use of magnetic valves with this setup.

A.3.2.3.1 Equipment configuration for Trial 1.1 through Trial 1.6 and for Trial 1.8

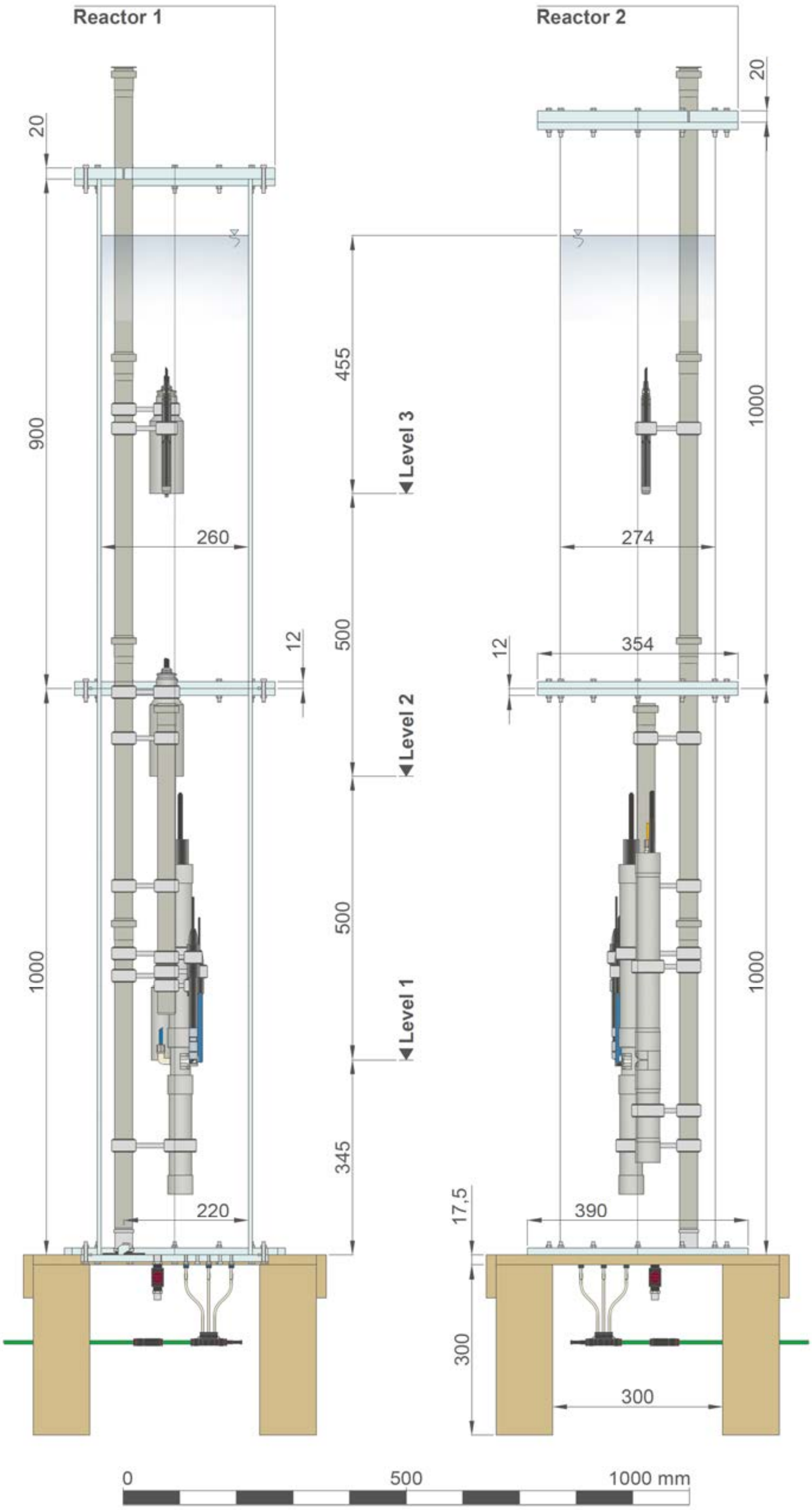


A.3.2.3.2 Equipment configuration for Trial 1.7

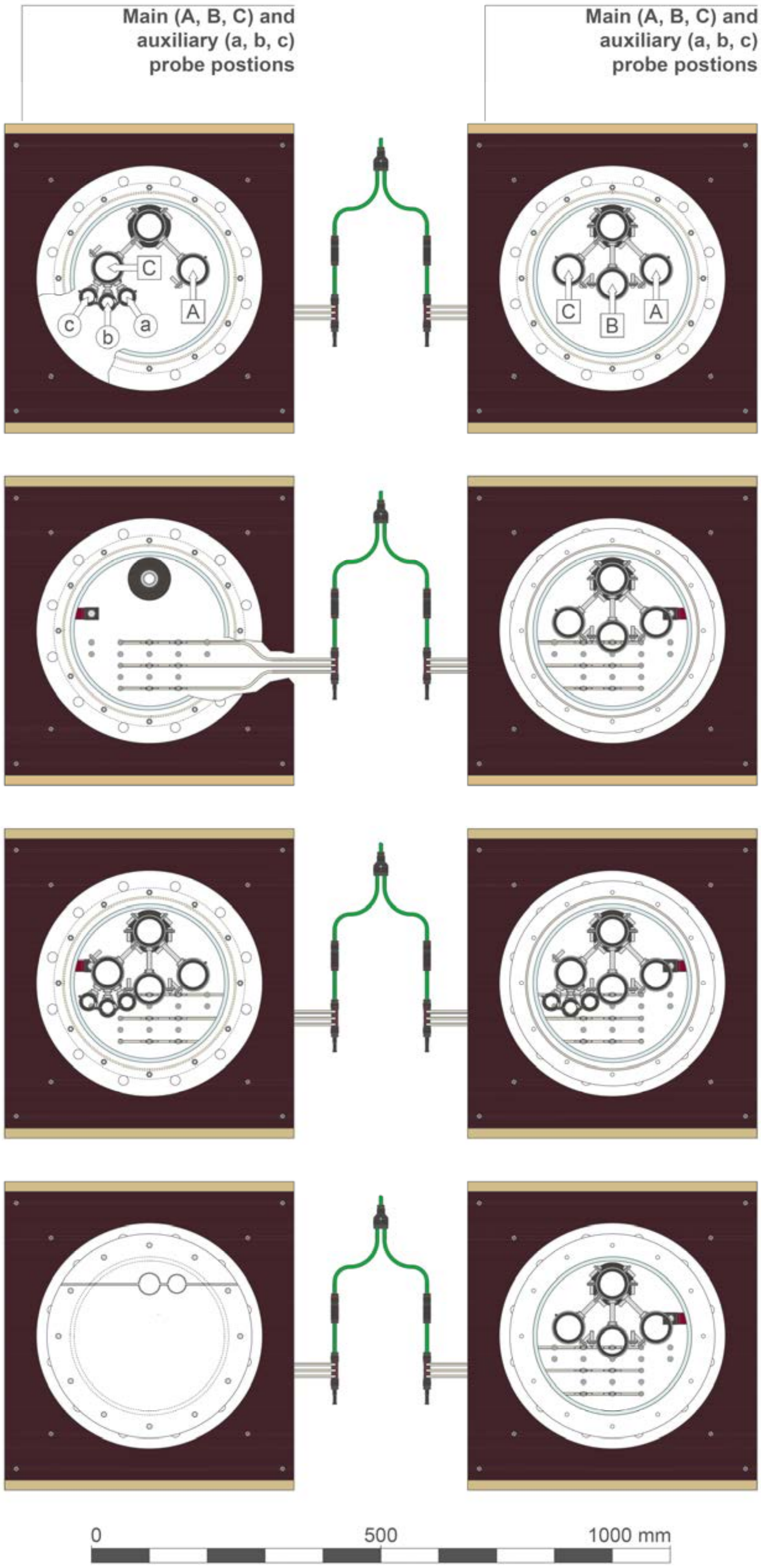


A.3.2.4 Setup for laboratory experiments of LAB 2

A.3.2.4.1 Vertical installation levels in reactors of the second generation

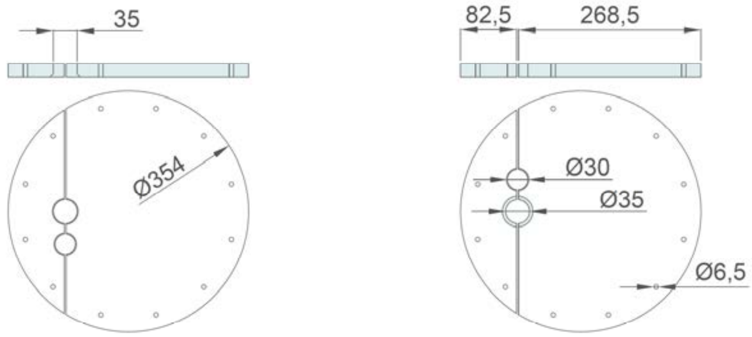


A.3.2.4.2 Horizontal installation positions and top view of bottom plate with the aeration system

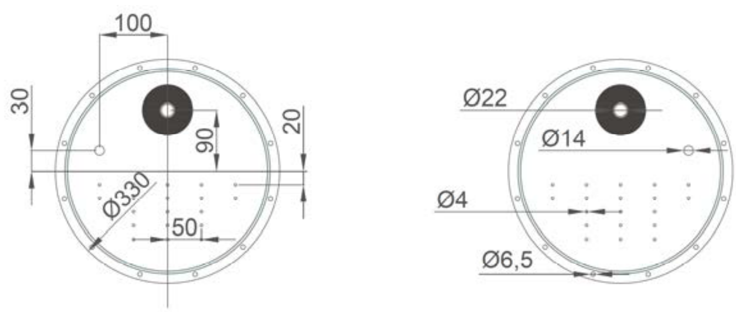


A.3.2.4.3 Reactor cover, bottom plate and substructure dimensions

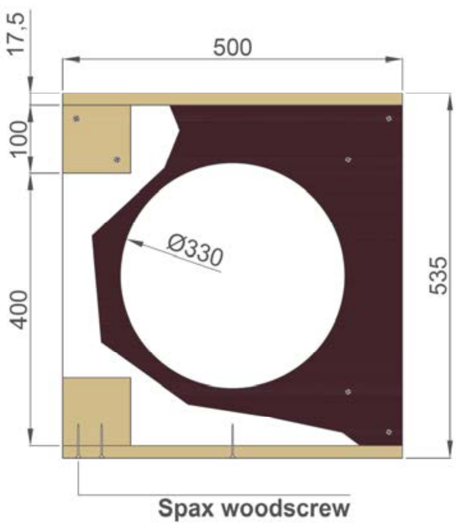
Split top lid- bottom view (left) and top view (right)

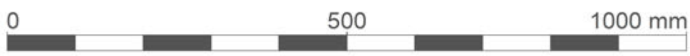


Bottom plates with borings and mandrel for probe mounting system and glued on rubber inlays for shock (crack) protection, grid for aeration borings

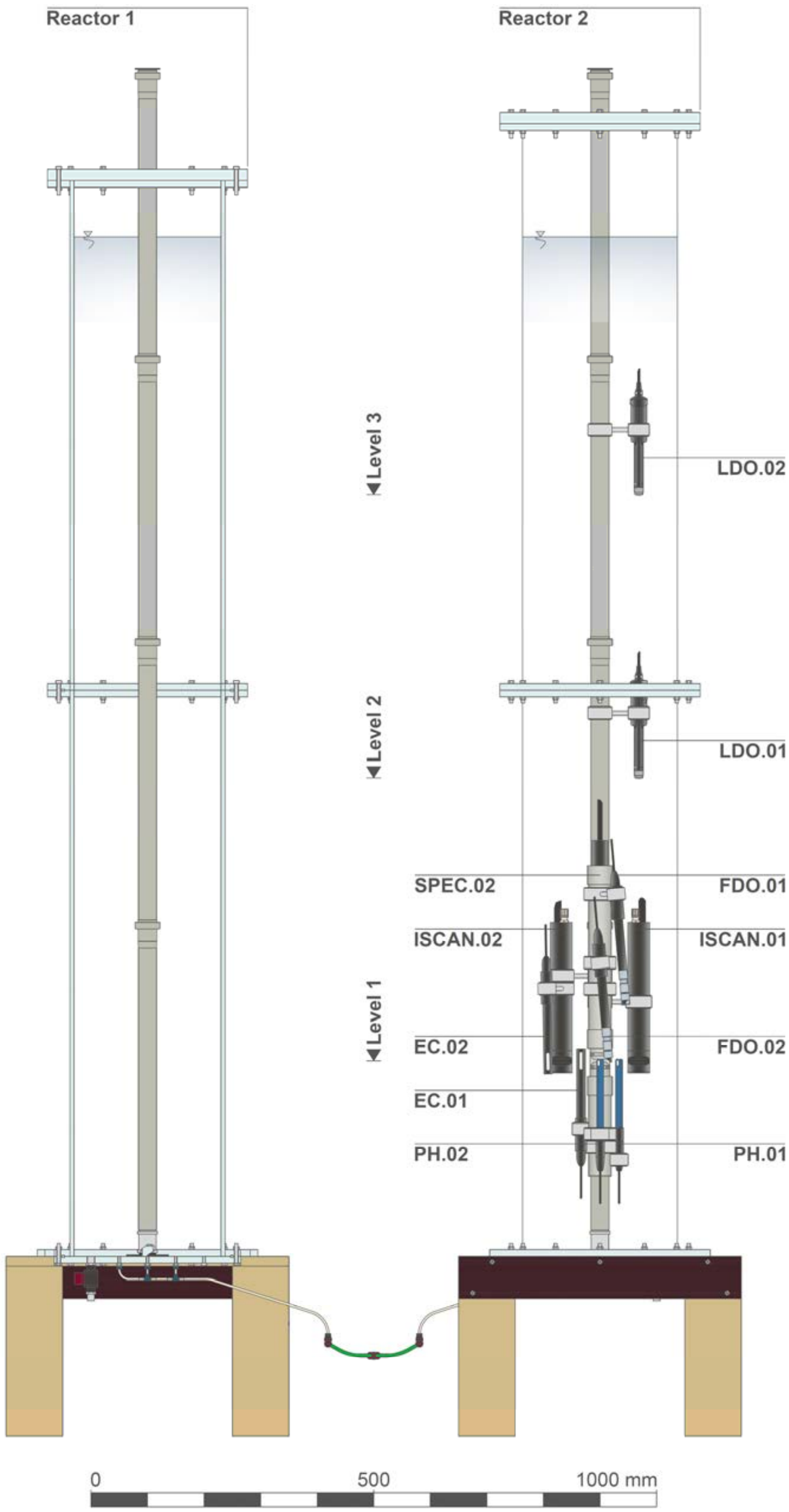


Top view of reactor substructure, sealed and laminated timber elements

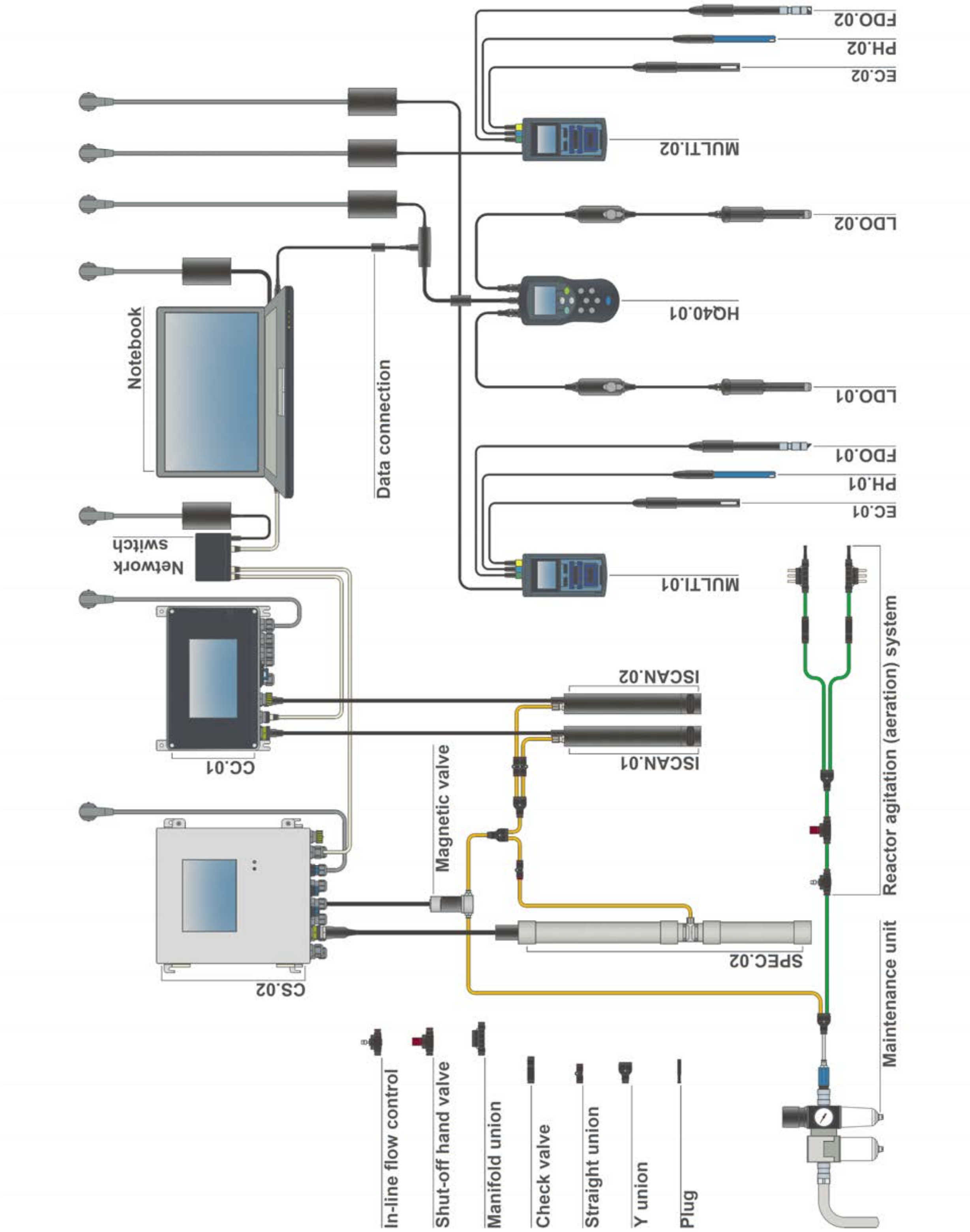




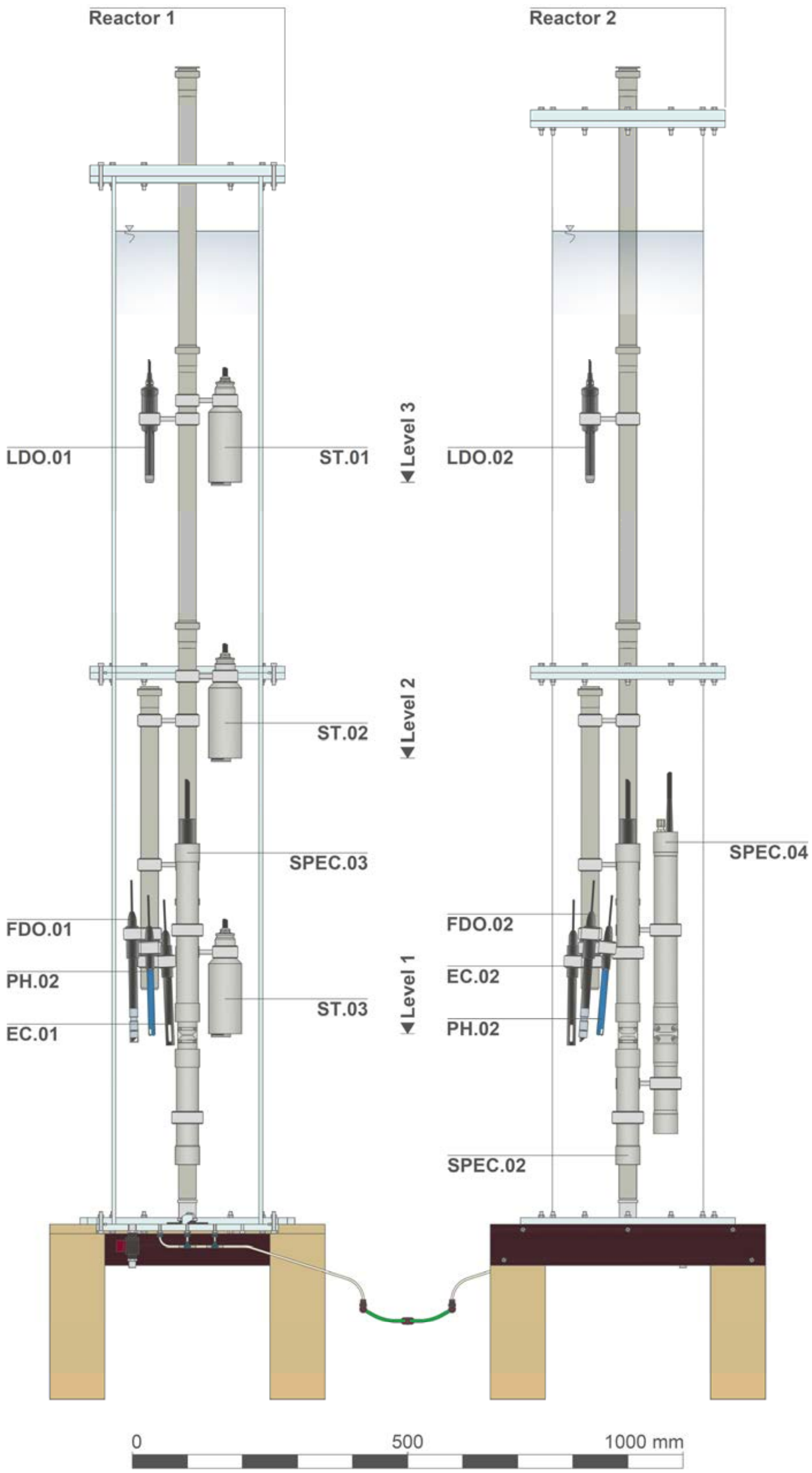
A.3.2.4.4 Probe placement for Trial 2.1



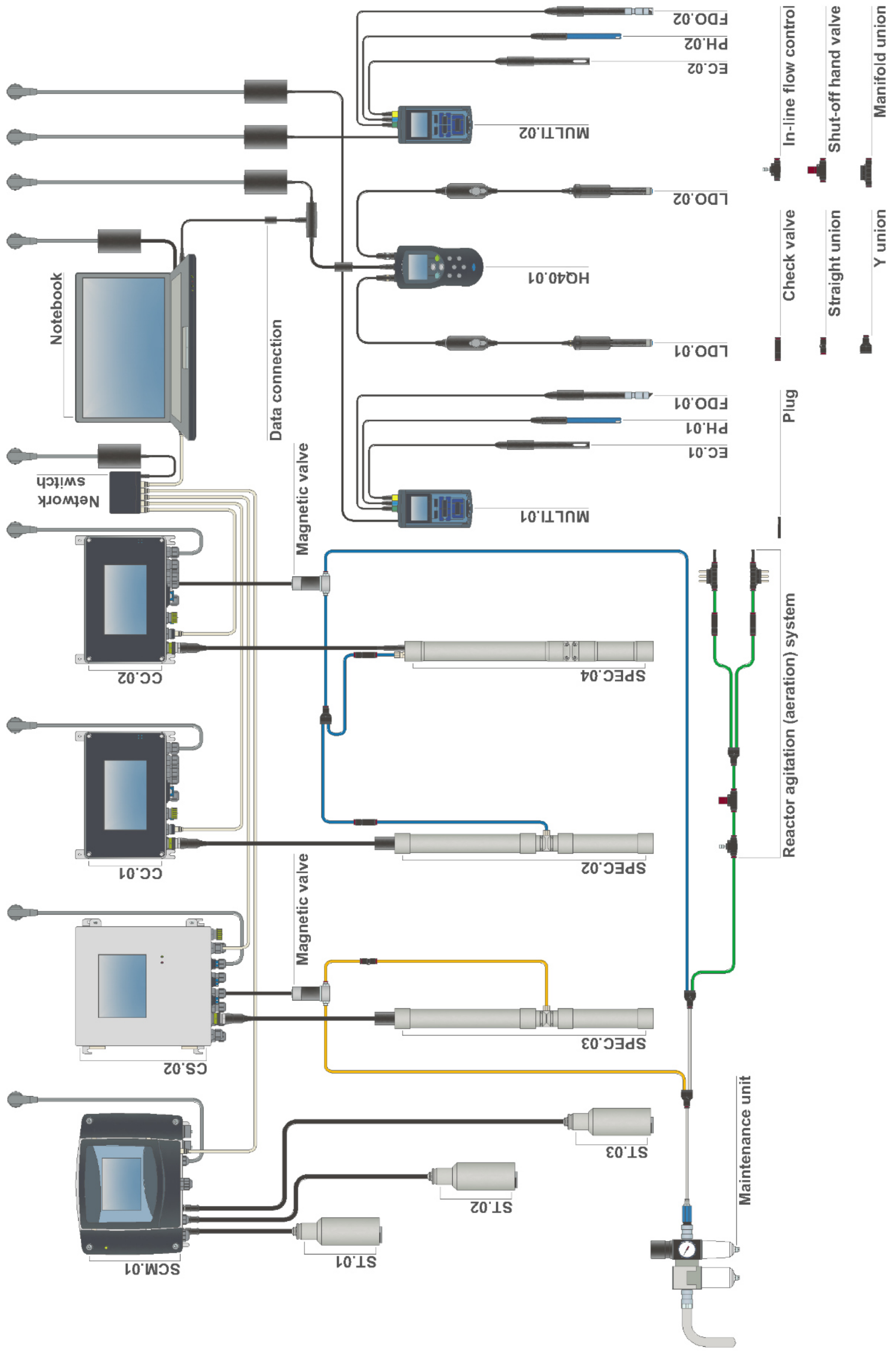
A.3.2.4.5 Equipment configuration for Trial 2.1



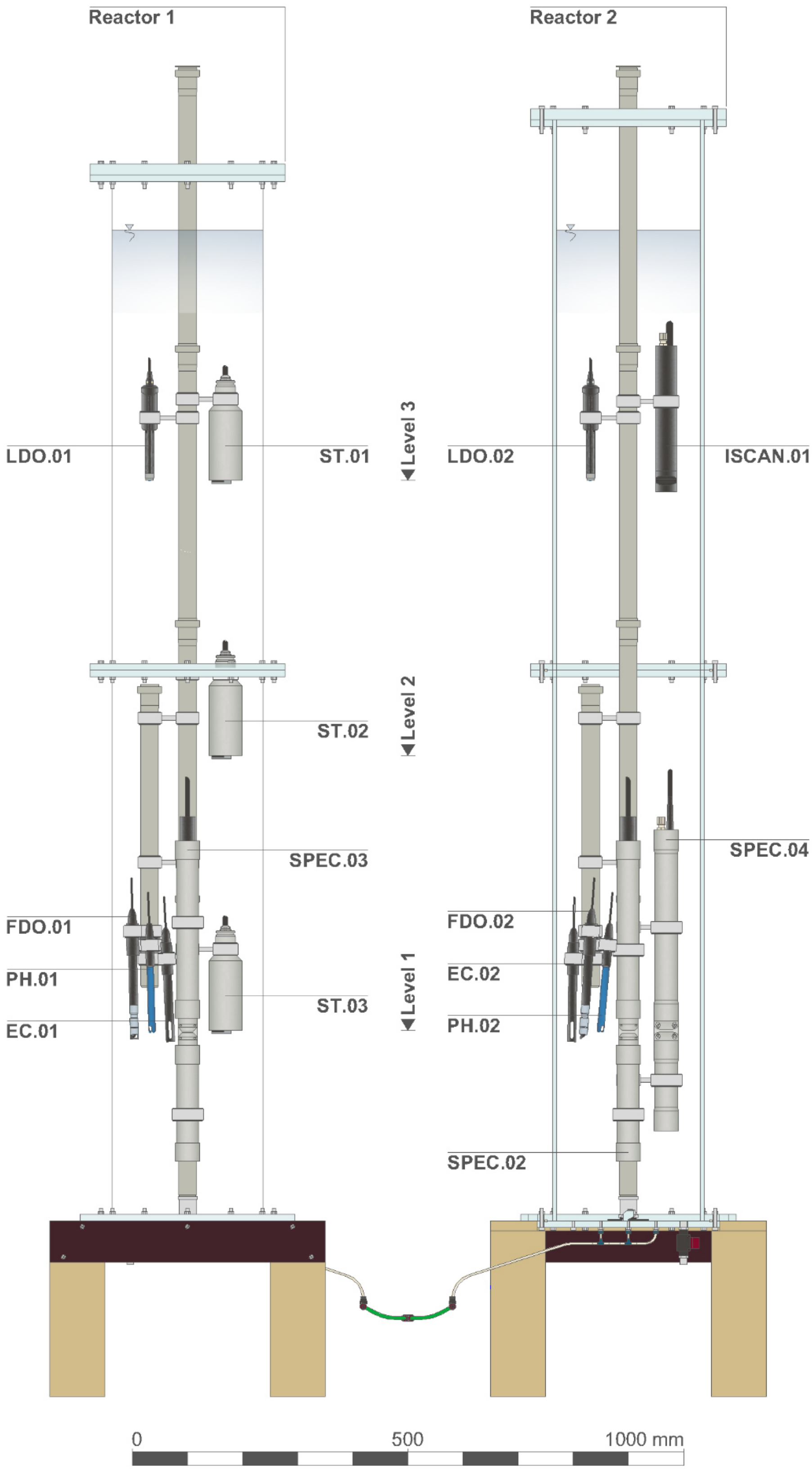
A.3.2.4.6 Probe placement for Trial 2.2



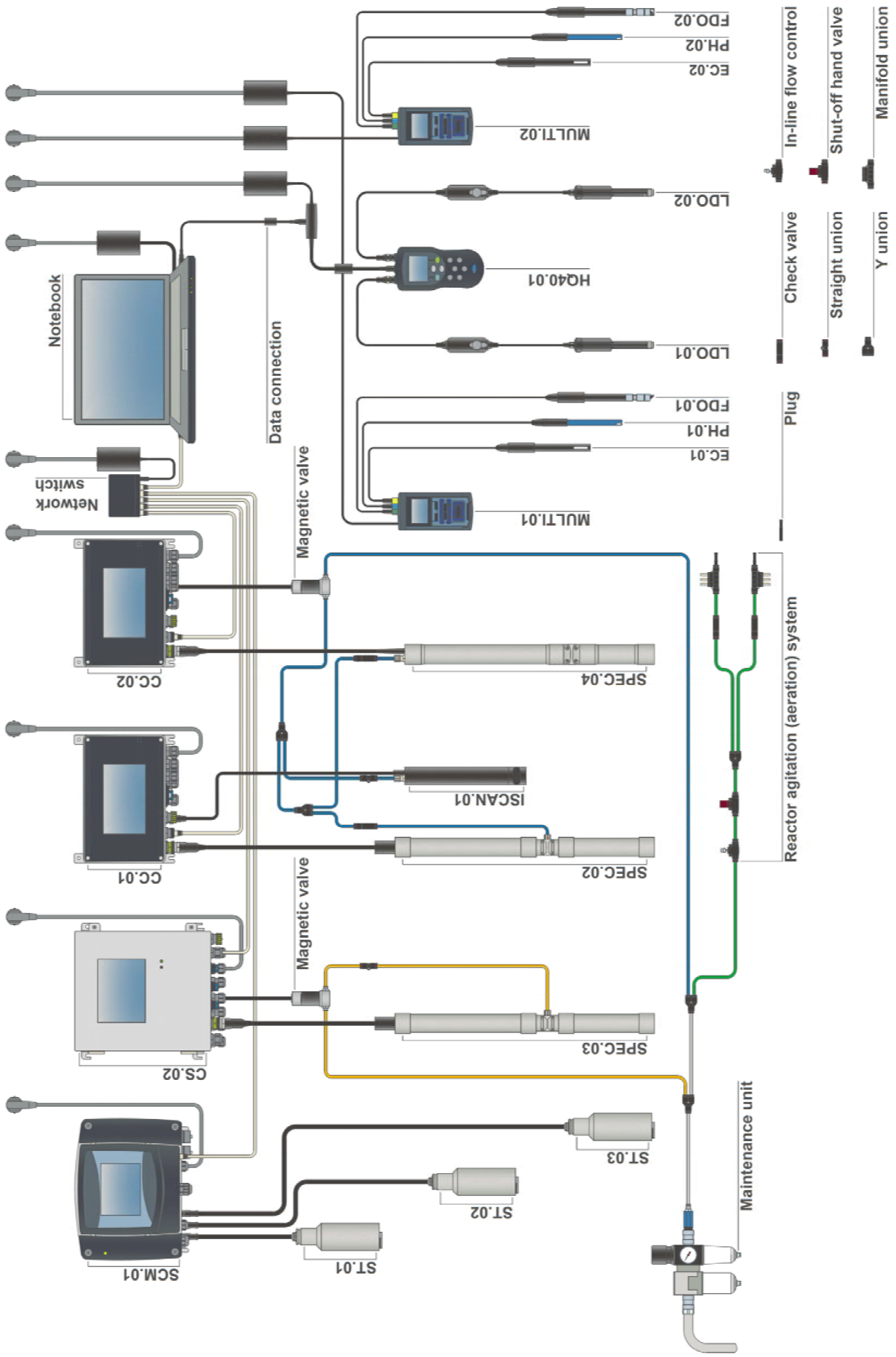
A.3.2.4.7 Equipment configuration for Trial 2.2



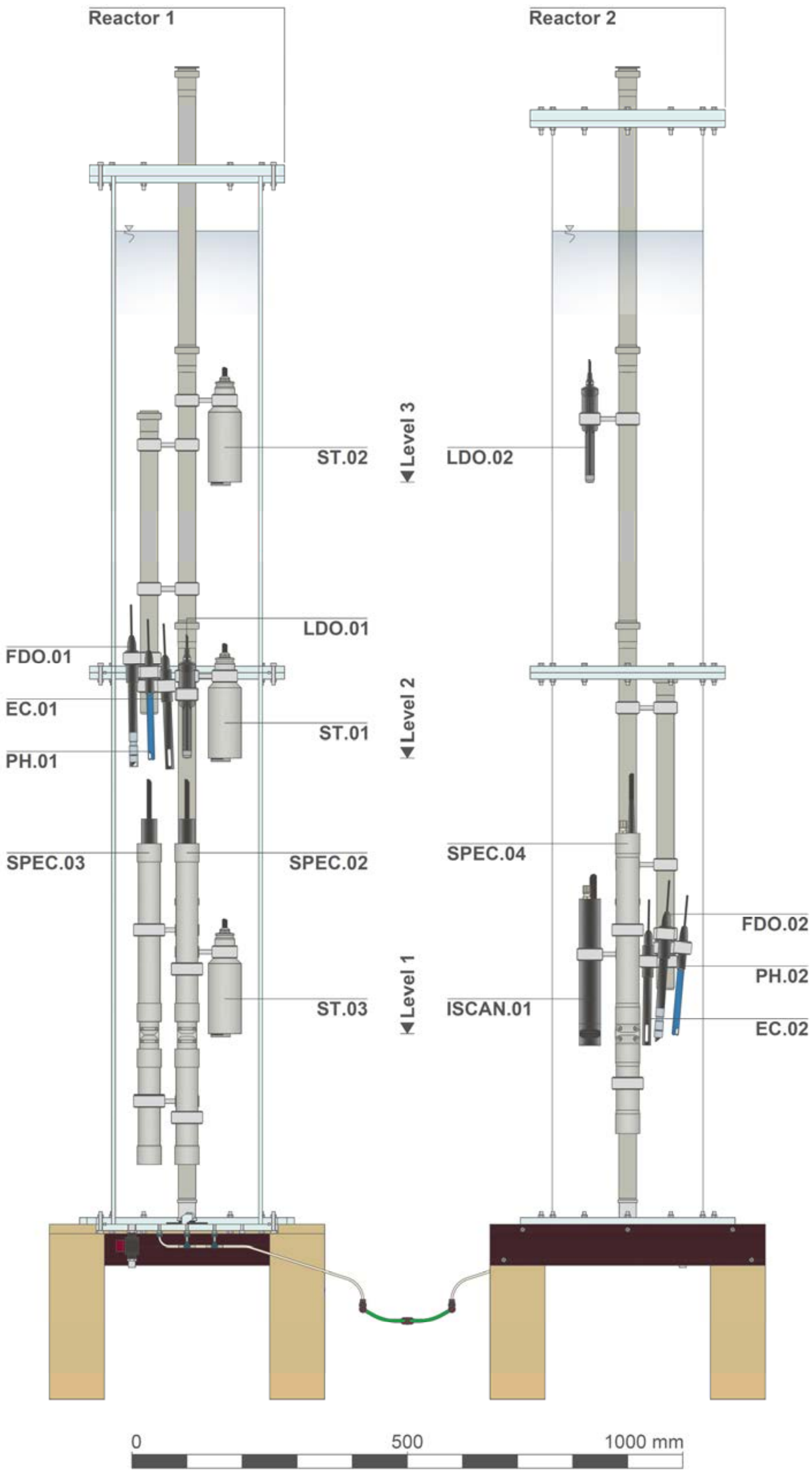
A.3.2.4.8 Probe placement for Trial 2.3



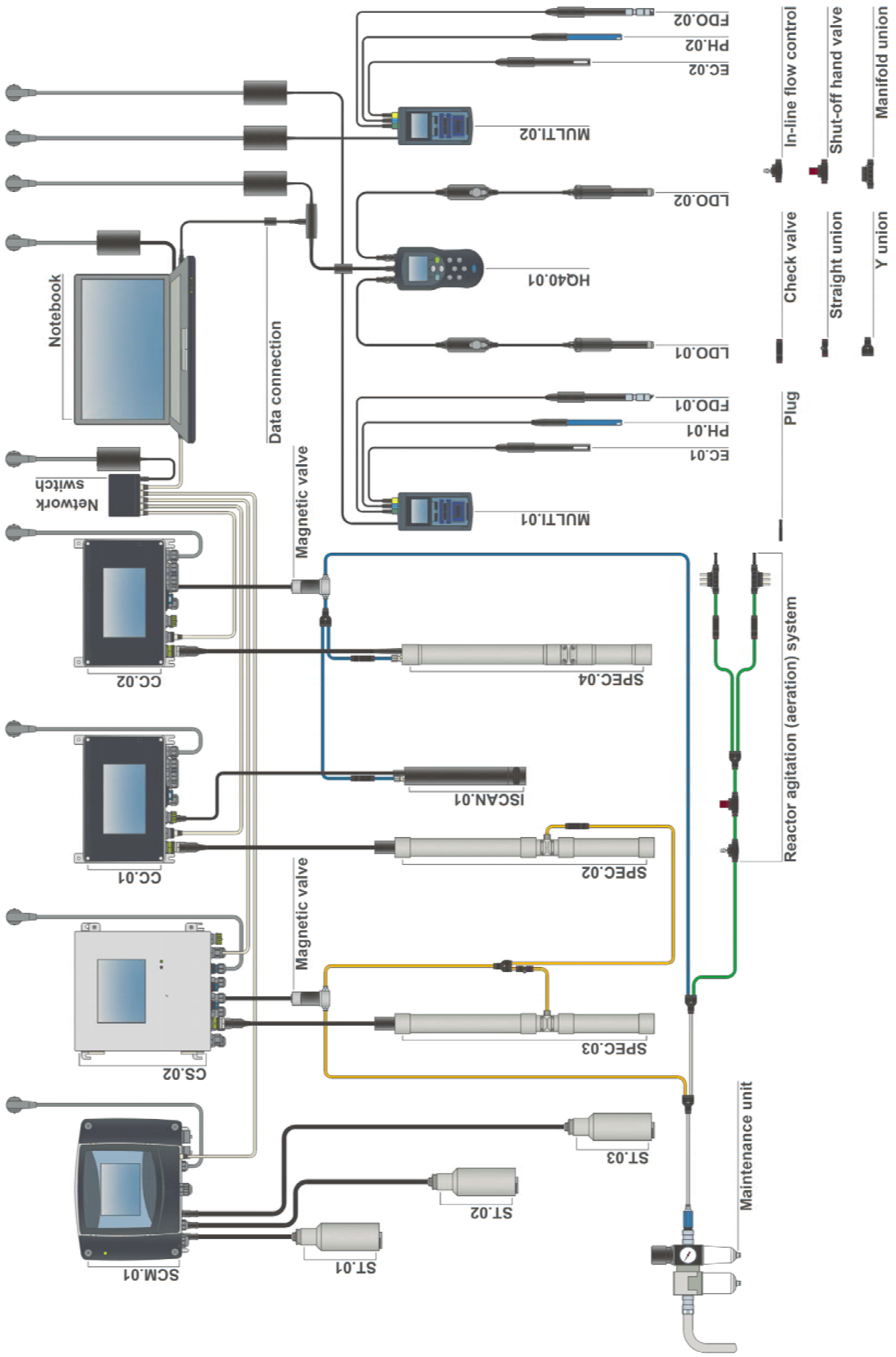
A.3.2.4.9 Equipment configuration for Trial 2.3



A.3.2.4.10 Probe placement for Trial 2.4



A.3.2.4.11 Equipment configuration for Trial 2.4



A.3.3 Operational data and equipment data for field testing programmes FIELD 0 and FIELD 1

The following section contains operational data, equipment configurations and corresponding system drawings for both field testing programmes.

A.3.3.1 Operational data for FIELD 0

Operational Data, Monitoring Station Graz-CST-CS1, Field Testing Programme FIELD 0 2014-07-01 – 2015-02-28																										
	Duration						Environment			Equipment																
										Installation Site:			CH								OV				CR	
										Probe ID:			SPEC.03		SOLI.01		COND.01		PWL.01		PWL.02		FLOD.01		PS.02	
Trial Identification	Overall Duration	Equipment Configuration	Days	Hours	Minutes	Seconds	Monitoring Installation	Submersion Medium (345[1] mm Threshold in Chamber)	System Manipulation	Primary Probes	Automatically Cleaned Primary Probes[2]	Secondary Probes	Installation Status	Maintenance	Installation Status	Maintenance	Installation Status	Maintenance	Installation Status	Maintenance	Installation Status	Maintenance	Installation Status	Maintenance	Installation Status	Maintenance
FT.0	242 d 23 h 58 m 00 s	1	02	10	30	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	30	00	Graz-CST-CS 1	AIR	MAN	1	3	5	-	IC	-	IC	-	IC	-	VI	-	VI	-	RM	-	VI
			12	22	30	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	30	00	Graz-CST-CS 1	AIR	MAN	1	3	5	-	IC	-	IC	-	IC	-	VI	-	VI	-	RM	-	VI
			06	22	00	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	04	00	00	Graz-CST-CS 1	AIR	MAN	1	3	5	-	IC	-	IC	-	IC	-	VI	-	VI	-	RM	-	VI
			05	20	30	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	30	00	Graz-CST-CS 1	AIR	MAN	1	3	5	INS	-	INS	-	INS	-	INS	-	INS	-	INS	-	INS	-
			01	00	00	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	44	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	26	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	50	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			05	20	58	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	19	58	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	03	32	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	44	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	22	58	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	42	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	00	34	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	02	18	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	10	08	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	02	56	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	06	00	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	08	46	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	20	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	08	56	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	24	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	30	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	20	36	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	56	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			05	05	32	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	04	18	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			04	02	04	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	00	00	Graz-CST-CS 1	AIR	MAN	1	3	5	-	IC	-	IC	-	IC	-	VI	-	VI	-	RM	-	VI
			08	01	36	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	14	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	09	04	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	04	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	02	44	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	16	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	21	36	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	40	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	00	04	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	34	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	10	48	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	24	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	21	40	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	02	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	02	06	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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FT.0	242 d 23 h 58 m 00 s	1	00	00	26	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	16	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	02	00	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	09	42	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	09	04	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	04	22	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	00	08	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	02	16	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	16	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	12	10	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	04	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	09	34	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	04	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	40	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	10	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	28	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			06	12	12	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	54	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	16	00	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	04	14	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			29	19	06	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	28	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	10	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	05	46	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			14	19	14	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	02	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	26	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	54	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	08	20	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	04	20	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	09	32	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	34	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	06	54	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	38	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	06	40	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	15	13	56	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	04	04	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	06	49	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	03	11	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	02	24	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	04	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	04	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			04	10	30	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	54	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	04	54	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	56	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			04	11	58	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	08	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	04	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	10	46	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	28	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	23	38	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	18	56	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	34	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	22	58	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	22	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	17	18	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	04	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	08	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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FT.0	242 d 23 h 58 m 00 s	1	01	09	04	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	05	40	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	21	10	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	19	08	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	04	54	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	10	06	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	12	18	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	14	54	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	17	20	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	10	18	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	09	12	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	11	16	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	04	52	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	28	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	21	14	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	04	48	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	14	12	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	02	06	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	05	18	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	08	24	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	22	08	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	16	06	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			03	02	52	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	15	24	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	22	46	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	15	28	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			03	01	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	15	54	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	24	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			03	03	60	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	17	10	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			03	03	12	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	16	18	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	19	54	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	16	10	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			03	00	34	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	15	26	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	04	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	20	14	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	01	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	16	30	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	10	38	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	21	26	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	11	56	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	08	22	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	17	06	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	22	18	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	10	14	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	01	26	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			07	02	26	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	12	44	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	06	36	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	16	56	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	00	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	16	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	16	28	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	16	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-

continued on next page

continued from previous page

FT.0	242 d 23 h 58 m 00 s	1	01	09	36	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	16	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	02	28	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	14	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	13	42	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	06	48	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	08	02	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	03	32	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	16	52	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	06	18	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	11	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	05	36	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	10	24	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	38	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	11	44	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	54	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	11	36	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	50	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			01	05	48	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	07	26	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	07	56	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			00	13	42	00	Graz-CST-CS 1	AIR	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			02	14	50	00	Graz-CST-CS 1	CWW	-	1	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1)] The threshold for event classification is based on the distance between the floor of the storage chamber at CS 1 and the centre of the measuring window of the spectrometer probe in the monitoring installation Graz-CST-CS1, amounting to a distance of 345 mm. The secondary probes behind the sheet metal cover of the station are submerged once the water level in the storage chamber of CS 1 surpasses 200 mm.

[2)] An additional probe with activated automatic cleaning was installed during FIELD 0. Though it is not considered in this thesis, its parallel operation with the equipment in Graz-CST- CS1, sharing a control unit, compressor and compressed air valve, as well as its compressed air lining of approximately 10 metres might have reduced the service pressure supplied to the probes of the installation inside the storage chamber of CS 1.

end of table

A.3.3.2 Equipment placement and configuration for FIELD 0

In accordance with the position assignments for the reactors of LAB 1 and LAB 2, a similar position nomenclature was implemented for field testing at monitoring station Graz-CST-CS1 during trial programme FIELD 0.

The vertical installation levels were assigned IDs from *Level 3* (installation at or near the ceiling if the chamber) to *Level 1* near the floor of the chamber. Level 0 represents installation in the control room above CS 1.

Horizontal positions are limited to two main positions, *A* and *C*. Position A is at the back wall of the chamber (installation site of the water quality monitoring equipment) and position C, which represents installation in the overflow section of control structure CS 1, in close proximity to the start of the overflow channel.

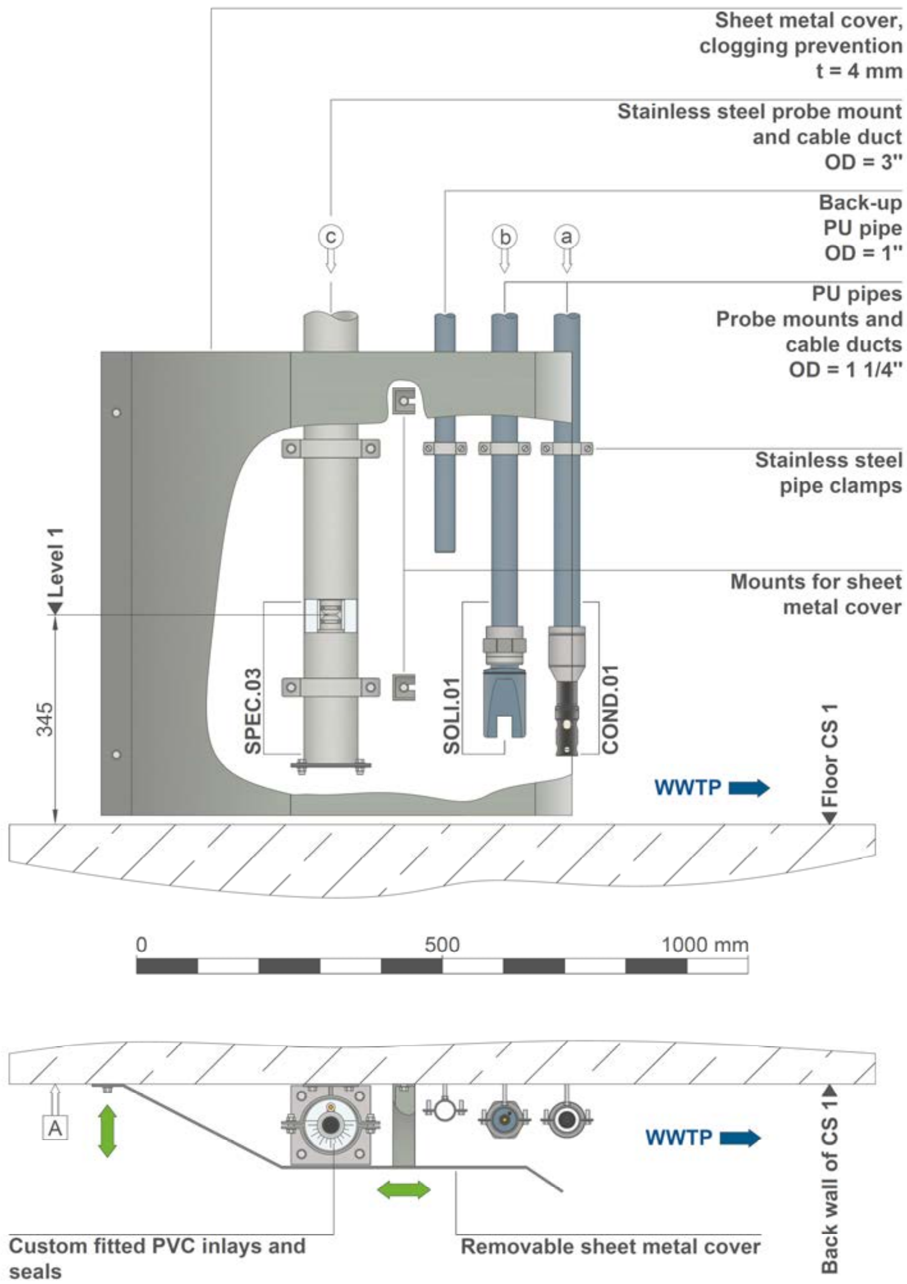
Auxiliary positions *a*, *b* and *c* were assigned to the current positions of the water quality probes in the existing installation, behind the sheet metal cover, as depicted in the following section.

Equipment Configuration and Probe Settings, Field Testing Programme FIELD 0 2014-07-01 – 2015-02-28																					
	Equipment Position and Connections, Basic Settings										Equipment Configuration 1										
												Automatic Probe Cleaning Settings (APCS)									
Trial ID	Monitoring Installation	Installation Site	Level	Main position	Auxiliary Position	Probe Inclination	Probe Identification	Probe Category	Control Unit ID (Data Logger ID)	Logger Interval¹⁾ [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Target Pressure¹⁾ [bar]	Wiper Status	Wiper Interval [sec]	
FT.0	Graz-CST-CS 1	CH	3	B	-	0	PWL.01	SEC	NVM.01 (CC.05)	120	NC	-	-	-	-	-	-	-	-	-	
		CH	1	A	a	0	SPEC.03	PRI	CC.05	120	δ	NV	ON	CA	900	3	?	4.5	-	-	
		CH	1	A	b	0	SOLI.01	SEC	CC.05	120	δ	NV	ON	CA	900	3	?	4.5	-	-	
		CH	1	A	c	0	COND.01	SEC	CC.05	120	δ	NV	ON	CA	900	3	?	4.5	-	-	
		OV	3	C	-	0	PWL.02	SEC	NVM.02 (CC.05)	120	NC	-	-	-	-	-	-	-	-	-	
		OV	3	C	-	0	FLOD.01	SEC	Module²⁾ (CC.05)	120	NC	-	-	-	-	-	-	-	-	-	
		CR	0	-	-	-	PS.02	SEC	CC.05	120	NC	-	-	-	-	-	-	-	-	-	

[1] Based on limited information and/or assumed values. [2] More detailed information was not available.

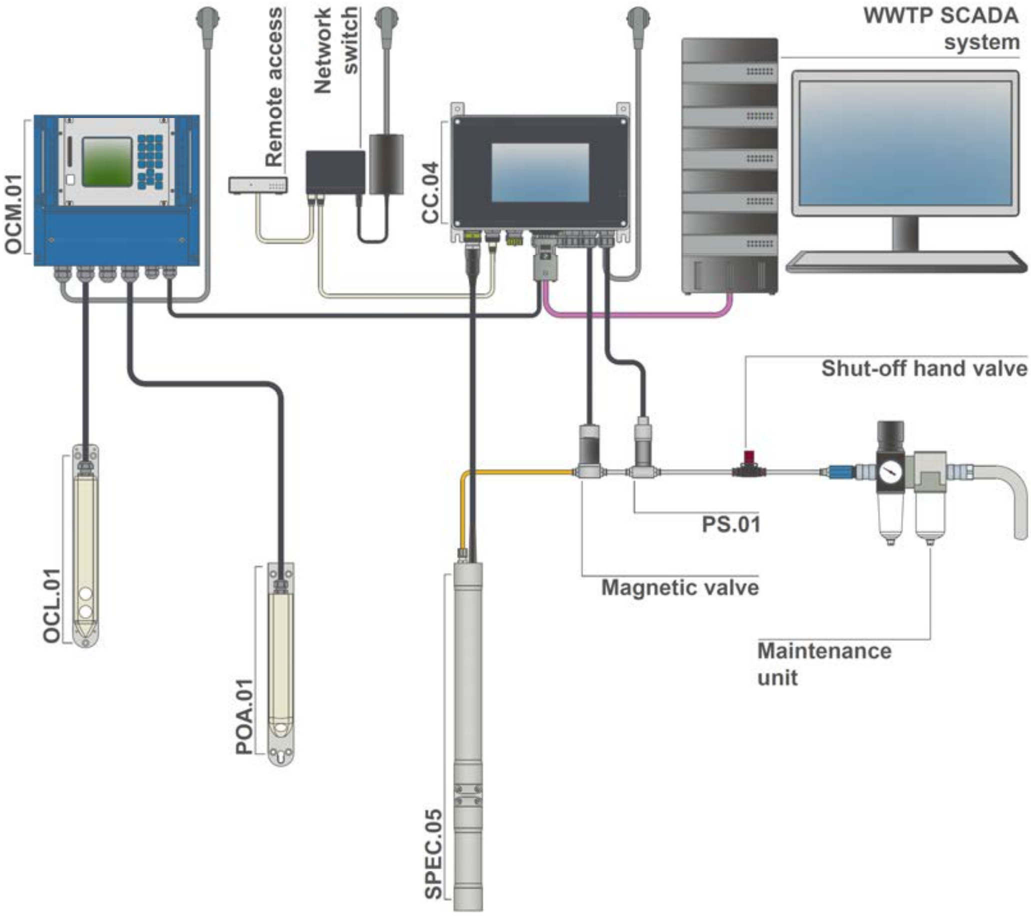
A.3.3.2.1 Probe placement for Trial FT.0

Distances in the following drawing are approximated from photos, plan snippets and the recollection of the staff members installing the equipment, with the exception of the distance between the floor of the storage chamber in control structure CS 1 and the centre of the measuring window of the spectrometer probe (SPEC.03). Due to limited access to the probes during testing period FILED 0 and a lack of suitable blue prints, obtaining more accurate measurements was not possible.



A.3.3.2.2 Equipment configuration for Trial FT.0

Probes marked with an asterisk in the following figure (SPEC*), despite being connected to control unit CC.05, are not used for data collection during trial FT.0. These probes are considered, since their results might influence the performance of the control unit or the automatic probe cleaning system of station Graz-CST-CS1. The raw data of probe SPEC* is included in the provided data set in Appendix B, but was not considered or processed beyond basic result combination and validation.



A.3.3.3 Operational data for field testing programme FIELD 1

Operational Data, Monitoring Station Graz- WWTP-CSO, Field Testing Programme FIELD 1 2016-05-01 - 2016-09-30																							
Trial Data			Duration				Environment and Sampling						Equipment										
													Installation Site:			OC						CR	
													Probe ID:			SPEC.05		OCL.01		SPEC.05		PS.01	
Trial ID	Trial Duration	Equipment Configuration	Days	Hours	Minutes	Seconds	Monitoring Installation	Submersion Medium (200 mm Threshold)	Grab Sample ID	Analytics Programme	Sample Volume (mL/Sample)	System Manipulation	Primary Probes	Auto. Cleaned Primary Probes	Secondary Probes	Installation Status	Maintenance	Installation Status	Maintenance	Installation Status	Maintenance	Installation Status	Maintenance
FT.1	149 d 00 h 00 m 00 s	1	04	09	00	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	02	30	00	Graz-WWTP-CSO	NFD	-	-	-	MAN	1	1	1	-	IC	-	-	-	-	-	IC
			08	01	30	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	01	30	00	Graz-WWTP-CSO	NFD	-	-	-	MAN	1	1	1	-	IC	-	-	-	-	-	IC
			07	20	30	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	01	30	00	Graz-WWTP-CSO	NFD	-	-	-	MAN	1	1	1	-	IC	-	-	-	-	-	IC
			18	19	54	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	05	36	00	Graz-WWTP-CSO	NFD	-	-	-	MAN	1	1	1	-	IC	-	-	-	-	-	IC
			02	19	40	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	03	20	00	Graz-WWTP-CSO	NFD	-	-	-	MAN	1	1	1	SER	IC	-	-	-	-	SER	IC
			03	20	30	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	02	30	00	Graz-WWTP-CSO	NFD	-	-	-	MAN	1	1	1	-	VI	-	-	-	-	-	VI
			07	19	00	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	01	50	00	Graz-WWTP-CSO	NFD	-	-	-	MAN	1	1	1	SER	IC	-	-	-	-	SER	IC
			00	23	10	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	09	00	00	Graz-WWTP-CSO	NFD	-	-	-	MAN	1	1	1	INS	RM	-	-	-	-	INS	RM
			00	00	02	00	Graz-WWTP-CSO	NFD	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
			00	13	58	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	00	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	VI	-	VI	-	VI	-	VI
			00	14	12	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	44	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			01	21	30	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	00	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			01	06	34	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	IC	-	RM	-	RM	-	IC
			07	02	30	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	03	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	IC	-	RM	-	RM	-	IC
			02	07	46	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	54	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	30	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	26	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	04	06	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	04	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	40	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	05	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	RPL	VI	-	VI	-	VI	RPL	VI
			04	16	18	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	04	12	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	IC	-	RM	-	RM	-	IC
			02	14	36	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	46	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	14	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	18	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			02	12	00	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	56	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	11	46	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	07	06	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	IC	-	RM	-	RM	-	IC
			00	04	38	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	44	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			02	12	26	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	04	00	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	IC	-	RM	-	RM	-	IC

continued on next page

continued from previous page

FT.1	149 d 00 h 00 m 00 s	1	00	03	54	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	46	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	14	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	24	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	26	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	14	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	14	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	18	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			03	11	30	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	RM	-	RM	-	RM	-	RM
			01	21	30	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	03	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	RM	-	RM	-	RM	-	RM
			05	19	00	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	00	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	RM	-	RM	-	RM	-	RM
			00	12	16	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	16	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	05	08	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	04	40	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	36	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	07	32	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	36	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	22	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			04	21	54	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	28	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	13	12	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	03	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	IC	-	RM	-	RM	-	IC
			00	13	22	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	34	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			01	22	42	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	42	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	06	40	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	02	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			02	15	16	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	54	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	05	38	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	05	19	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	REP	IC	-	RM	-	RM	REP	IC
			06	21	21	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	VI	-	VI	-	VI	-	VI
			00	07	16	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	42	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	16	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	18	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	20	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	28	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			06	10	40	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	VI	-	VI	-	VI	-	VI
			00	01	08	00	Graz-WWTP-CSO	CWW	FT.1-1/2/3/4	4	1500	MAN	1	1	3	-	VI	-	VI	-	VI	-	VI
			00	00	22	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	VI	-	VI	-	VI	-	VI
			06	20	56	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	03	34	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	IC	-	RM	-	RM	-	IC
			05	08	12	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	56	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			01	08	58	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	00	28	00	Graz-WWTP-CSO	CWW	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	01	56	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	VI	-	VI	-	VI	-	VI
			07	21	30	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-
			00	02	30	00	Graz-WWTP-CSO	AIR	-	-	-	MAN	1	1	3	-	IC	-	RM	-	RM	-	IC
			03	14	00	00	Graz-WWTP-CSO	AIR	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-

[1)] The threshold for probe submersion is the vertical distance between the floor of the sewer at station Graz-WWTP-CSO and the centre of the measuring window of the spectrometer probe at the bottom of the float.

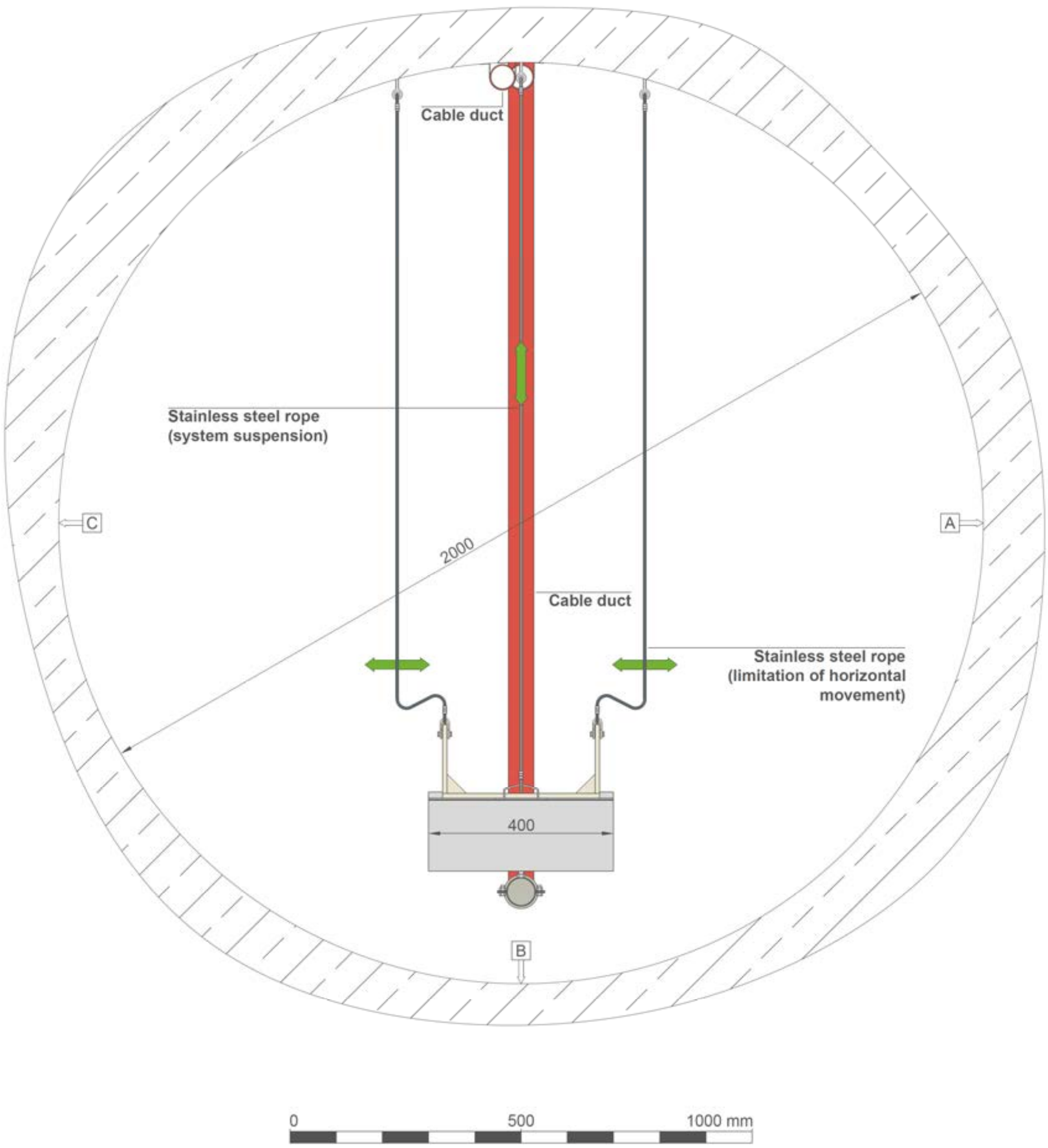
end of table

A.3.3.4 Equipment placement and configuration for FIELD 1

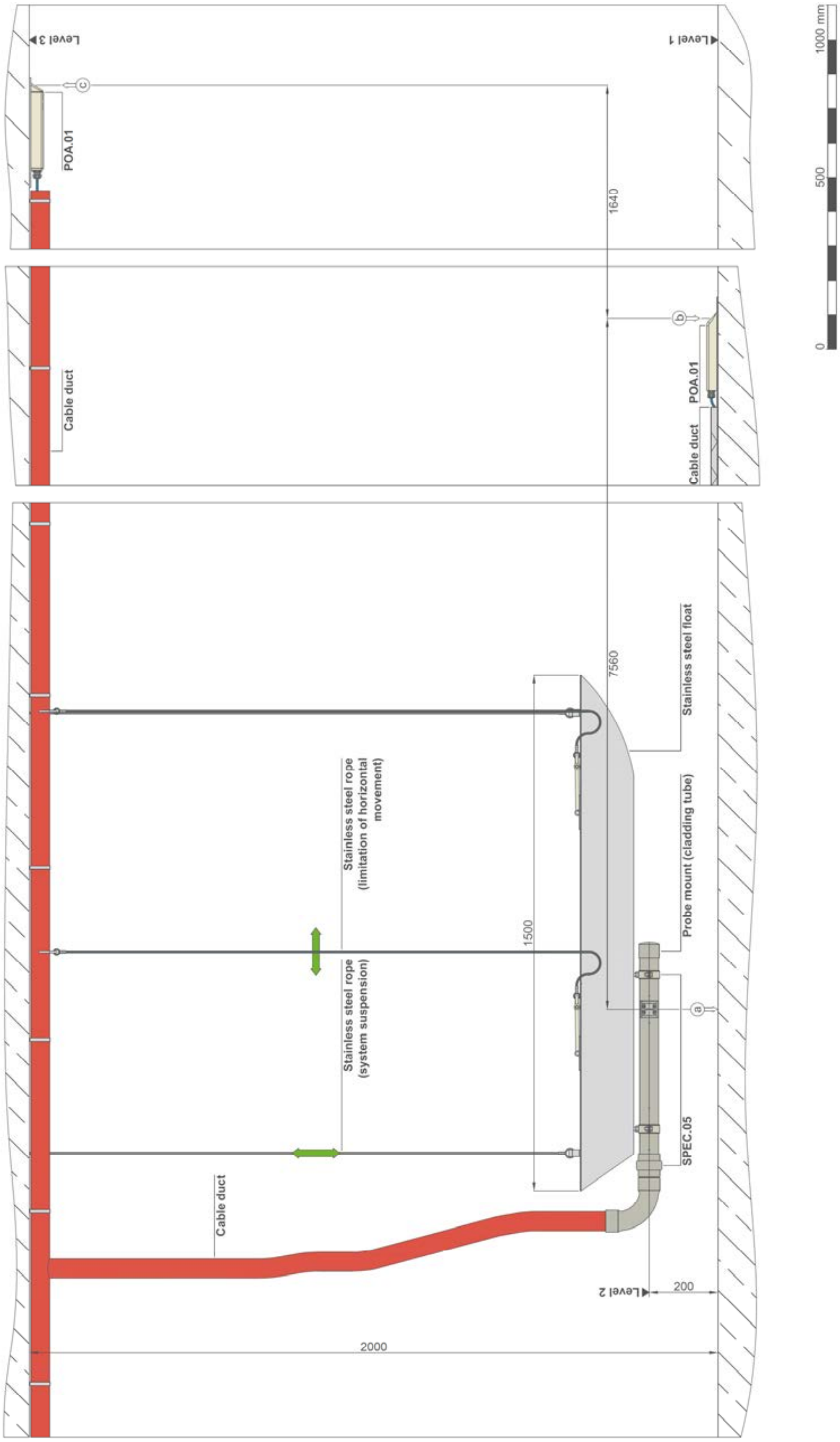
Equipment Configuration and Probe Settings, Field Testing Programme FIELD 1 2016-05-01 - 2016-09-30																					
	Equipment Position and Connections, Basic Settings										Equipment Configuration 1										
												Automatic Probe Cleaning Settings (APCS)									
Trial ID	Monitoring Installation	Installation Site	Level	Main Position	Auxiliary Position	Probe Inclination [°]	Probe ID	Probe Category	Control Unit ID (Data Logger ID)	Logger Interval [sec]	Manual Cleaning Status	Valve	Status	Medium	Interval [sec]	Duration [sec]	Gap [sec]	Target Pressure* [bar]	Wiper Status	Wiper Interval [sec]
FT.1	Graz-WWTP-CSO	**OV**	3	B	b	0	OCL.01	SEC	OCM.01 (CC.04)	120	δ	-	-	-	-	-	-	-	-	-
		OV	2	B	a	+90	SPEC.05	PRI	CC.04	120	δ	NV	ON	CA	900	3	10	4	-	-
		OV	1	B	b	0	POA.01	SEC	OCM.01 (CC.04)	120	δ	-	-	-	-	-	-	-	-	-
		CR	0	-	-	-	PS.01	SEC	CC.04	120	NC	-	-	-	-	-	-	-	-	-

A.3.3.4.1 Operational environment for Trial FT.1

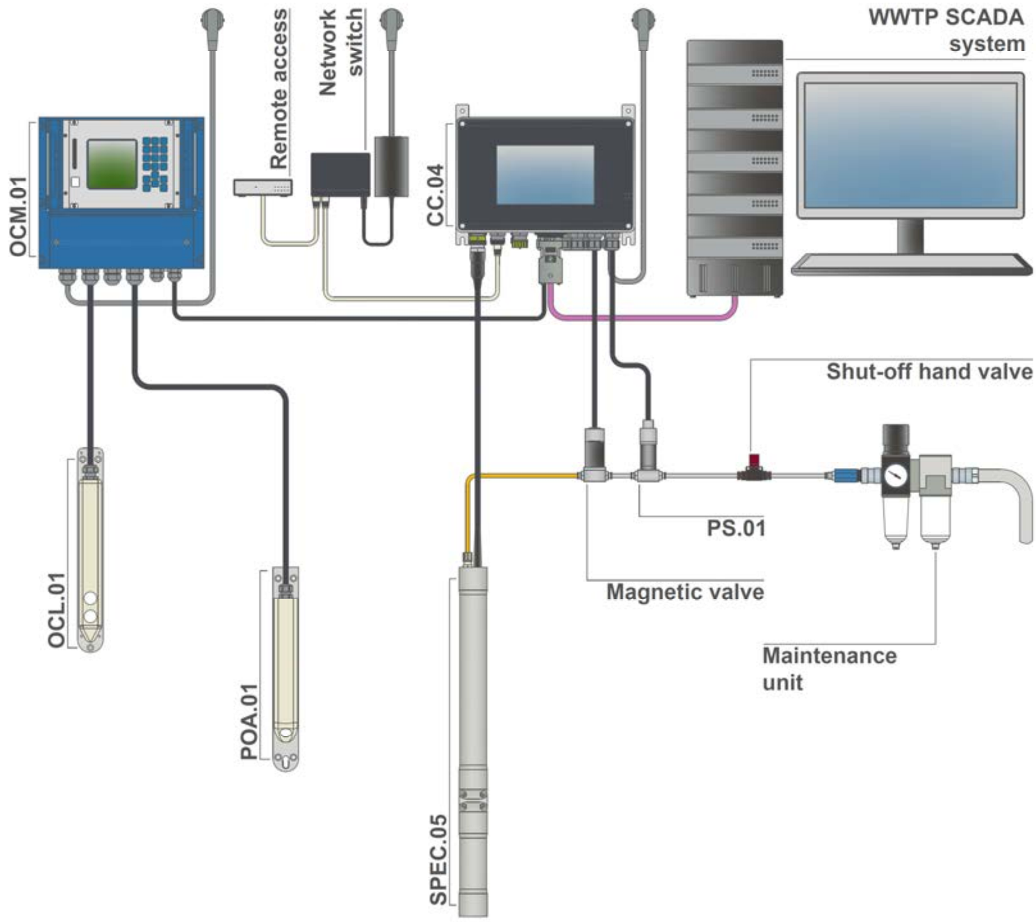
A.3.3.4.1.1 Front view of the floating pontoon for Trial FT.1



A.3.3.4.1.2 Elevation of the pontoon and the secondary probes for Trial FT.1



A.3.3.4.2 Equipment configuration for Trial FT.1



Appendix B

Appendix B contains the entire data set generated in the course of writing this thesis. Metadata, probe data, data describing the operational environments (laboratory reactors and field installation sites) are compiled in the form of a digital copy. Data is provided in raw and processed form. Additionally, all *R*-scripts used to process the results are made available.

Directory *Appendix_B* on the storage medium at the end of this thesis holds a subdirectory named *processing_environment*, which contains the entire data from laboratory and field trials. Inside are three subdirectories containing the file structure used for data processing and -plotting. This file structure is hard coded in the supplied *R*-scripts. After copying these directories (e.g. *data_processing_field _0*) on a local drive and adjusting the name of the working directory in the scripts in subdirectory *code*, the entire work flow for data processing and data visualisation at the core of this thesis can be replicated.

A file tree depicting the hierarchy of subdirectories within directory *Appendix_B* on the storage medium containing the digital appendices can be found on the following page.

- **Appendix_B**
  - **processing_environment**
    - data_processing_lab
    - data_processing_field_0
    - data_processing_field_1
  - **r_scripts**
    - data_processing
      - LAB_1_LAB_2
      - FIELD_0
      - FIELD_1
  - **metadata**
    - LAB_1_LAB_2
    - FIELD_0
    - FIELD_1
  - **raw_probe_data**
    - LAB_1
    - LAB_2
    - FIELD_0
    - FIELD_1
  - **processed_data**
    - reactor_environment_data
      - LAB_1_LAB_2
      - FIELD_0
      - FIELD_1
    - probe_data
      - LAB_1_LAB_2
      - FIELD_0
      - FIELD_1

Appendix C

Appendix C contains digital copies of the figures used for data visualisation and analysis. In addition to these time-series-plots, the *R*-scripts used to generate them are supplied. For easy replication of the plotting process in the *R* programming language, see directory *processing_environment* on the storage medium holding the digital appendices and the instructions in chapter Appendix B.

Additionally, figures, pictures and videos of operational setups, equipment configurations and reactor states are combined in this subsection of the appendix.

A file tree depicting the hierarchy of subdirectories within directory *Appendix_C* on the storage medium at the end of this work can be found on the following page.

- **Appendix_C**
  - **r_scripts**
    - data_visualisation
      - LAB_1_LAB_2
      - FIELD_0
      - FIELD_1
  - **time_series**
    - LAB_1_LAB_2
    - FIELD_0
    - FIELD_1
  - **system_figures**
  - **media_files**
    - pictures
      - LAB_1
      - LAB_2
      - FIELD_0
      - FIELD_1
    - videos
      - LAB_1
      - LAB_2
      - FIELD_0
      - FIELD_1