DESSIN

DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

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D31.1: Emscher Demonstration: Improving water quality in the strongly urbanised Emscher area

Conclusions from successful demonstration and specifications for final design

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The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039

DESSIN

EMSCHER GENOSSENSCHAFT

TITLE OF THE REPORT

DEL 31.1: CONCLUSIONS FROM SUCCESSFUL DEMONSTRATION, AND SPECIFICATIONS FOR FINAL DESIGN
Conclusions from successful demonstration, and specifications for final design of the solutions in T21.1 and T21.4 and documentation of their respective performance

SUMMARY

The EU project DESSIN investigates the effects that innovative technologies in the water sector can have on the services aquatic ecosystems provide for society. Part of the project is the demonstration of innovative technologies which can improve water quality. The present deliverable reports on the outcome of the demonstration. Impact of the innovative technologies on ecosystem services is evaluated and analyzed in terms of sustainability. This is covered in deliverable D31.2.

In the Emscher case study area (Germany), innovative water treatment technologies have been tested in combined sewer systems. These technologies can minimize the discharge of pollutants into water bodies during rain events with positive effects on the water quality of receiving water bodies. The streams' water quality, in turn, is directly related to various ecosystem services. As an innovative technology for decentralized treatment at Combined Sewage Overflows (CSOs), a container setup of a lamella settler was tested. In parallel, a real time control (RTC) system was experimentally implemented in a section of the sewer system.

The cross-current lamella settler was tested from June 2015 to Mai 2016 in Castrop-Rauxel (Germany). Its efficiency was found to be dependent of the flow rate, particle concentration at inflow as well as particle type. Maximal potential efficiencies of 37 % (total organic carbon (TOC)), 17 % (chemical oxygen demand (COD)), 22 % (total suspended solids, fine (TSS fine)) and 19 % (TSS) were detected. In an upscaling example to a large-scale CSO, overflow load reductions of 5.9 to 17.2 % were predicted.

The ADESBA-RTC of the sewer network was implemented at 5 CSO facilities in Dortmund in June 2016 and was operated from April to November 2017. New visualization interfaces and reporting templates were developed and, in parallel to real-life operation, the system was modelled in Simba# to compare behavior with ADESBA (real-life) and without (modelled). Reductions in overflow volume of up to 37.3 % were detected. In an analysis of potential for the entire sub-catchment of the wastewater treatment plant (WWTP) Dortmund Deusen, potential reductions of overflow volume of 3.8 to 7.5 % were modelled.

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DELIVERABLE NUMBER	WORK PACKAGE
D31.1	WP31
LEAD BENEFICIARY	**DELIVERABLE AUTHOR(S)**
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PLANNED DELIVERY DATE	**ACTUAL DELIVERY DATE**
31/12/2017	20/02/2018

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List of Acronyms and Abbreviations

ADESBA	Adaption und Entwicklung einer vorkonfektionierten Steuerungsbox zur Abflussteuerung von Kanalnetzen, basierend auf innovativen Kommunikationsmedien (German name and acronym of the RTC solution tested)
CAD	Computer-aided design
COD	Chemical oxygen demand
CSO	Combined sewer overflow
DN	Diameter
EG	Emschergenossenschaft
ifak	Institut für Automation und Kommunikation e.V.
MFM	Magnetic flowmeter
PLC	Programmable logic controller
RTC	Real Time Control
SEGNO	Segno Industrie Automation
TOC	Total organic carbon
TSS	Total suspended solids
TSS fine	Fraction of TSS < 63 µm
UFT	Umwelt- und Fluid-Technik Dr. H. Brombach GmbH
UDE	University of Duisburg-Essen
WFD	European water framework directive
WWTP	Wastewater treatment plant

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Executive summary

In the Emscher demonstration case study, two innovative technologies, which can improve water quality, have been tested. The present deliverable D31.1 reports on the outcomes of the testing. In the follow-up deliverable D31.2, the impact of the innovative technologies on ecosystem service provision and use is evaluated. Furthermore, the implementation of the two technologies is analyzed in terms of sustainability.

In the Emscher case study, innovative water treatment technologies have been tested in combined sewer systems. As an innovative technology for decentralized treatment at combined sewer overflows (CSOs), a container setup of a novel cross-flow lamella settler was tested. In the same time period, the real time control (RTC) system ADESBA was experimentally implemented in a section of the sewer system.

The sedimentation efficiency of the lamella settler was assessed by measuring inflow and overflow concentrations in the container setup (a container solution). The following main parameters were detected: Filterable substances and fine-grained filterable substances (Total suspended solids (TSS), fine total suspended solids (TSS fine)), chemical oxygen demand (COD) and total organic carbon (TOC). These parameters were monitored via two different monitoring approaches: Via special sensors (probes of the company s::can) conducting continuous measurements and providing data online, and in parallel via an automated sampler taking samples with tubes and storing them in cooled containers for subsequent chemical analysis in the laboratory. The differences between the inflow and overflow concentrations give indication of the sedimentation efficiency inside the lamella container. The main findings were that the efficiency is dependent on the flow rate. The lamella settler has the highest efficiency at a flow rate of 10 l/s and lower. Furthermore, the efficiency depends on the inflow concentration. The container starts to be efficient at an inflow concentration threshold of approximately 300 mg/L COD, for instance. The maximal potential efficiency assessed in the current setup is 37 % (TOC), 17 % (COD), 22 % (TSS fine) and 19 % (TSS). Thus, the particle concentration and type is of high importance for the efficiency. Based on these results, an upscaling to a large-scale CSO was conducted. Here, annual overflow load reductions of 5.9 to 17.2 % were predicted.

The efficiency of the ADESBA-RTC is represented by a reduction of the overflow volume into receiving streams. This efficiency was determined in different ways. At first, an analysis of potential was conducted for five CSO facilities, which were selected for testing of the RTC. Here, a potential reduction of 7.8 % of the overflow volume of the five CSOs was identified. Following the analysis of potential, the ADESBA-RTC was implemented in the five CSO facilities, controlled by an ADESBA-PC located in a central office. The operational data of the real-time controlled system during rain events were recorded and evaluated by an analysis of success. For this analysis, a comparison with the same system without ADESBA-RTC, which was simulated in the Simba# model, was conducted. This comparison revealed efficiencies of -16.6 to 37.3 % reduction in overflow volume.

Both technologies can minimize the discharge of pollutants into water bodies during rain events with positive effects on the water quality of receiving water bodies. The streams' water quality, in turn, is directly related to various ecosystem services.

1. Emscher case introduction

1.1. Problem description

In Europe, a large percentage of urban drainage systems are combined sewer systems, particularly in larger cities. This means that during rain events, the rain water enters the wastewater sewers and becomes mixed with domestic and industrial wastewater. The resulting combined sewage is then treated at wastewater treatment plants (WWTP). Combined sewer systems have a number of advantages but also disadvantages. They require lower investment and maintenance costs because only one sewer needs to be built and maintained. However, in order to take up large volumes of rainwater, additional storage tanks or sewers need to be constructed as part of the sewer network. Nevertheless, during heavy rain events, the amount of wastewater and rainwater at times exceeds this available storage volume in the sewer system and its underground storage basins. This results in combined sewer overflow events (CSO events) into nearby recipient waters or streams (Figure 1). Such overflow represents a kind of emergency release. Overflow points are located at large storage facilities, so called CSO facilities or tanks. During water storage, these facilities provide a certain degree of treatment to the combined sewage resulting from settling and sedimentation processes in the storage basins. Nevertheless, the overflowing water still contains particulate substances, to which particle-bound nutrients and contaminants can adhere, sewage garbage as well as dissolved contaminants and nutrients. Overflowing combined sewage can, thus, have negative effects on the aquatic ecosystems and the ecosystem services they provide, which is discussed in deliverable D31.2.

Figure 1 Combined sewer overflow discharging combined sewage into a nearby receiving stream.

As part of the ongoing river restorations in the Emscher basin, a total length of about 400 km of sewers and 290 CSO structures with a total volume of 485.000 m³ have been and still are to be built until 2017. Thus, the freshly restored Emscher tributaries and main stem (will) have to tolerate occasional CSO events. The pressures originating from CSO should therefore be minimized.

1.2. Possible solutions

DESSIN worked on innovations in improved decentralized treatment of combined sewage and in Real Time Control (RTC) of sewer systems. Both have the aim to reduce pollutant input into streams, either by reducing the contamination in the overflowing water or by reducing the overflow frequency and volume, respectively.

1.2.1. Decentralized water treatment

A novel decentralized water treatment technology aims at increasing sedimentation efficiency inside underground combined sewer storage structures/basins. This increase is aimed at through the insertion of cross-flow lamella modules inside these basins. The aim is to reduce pollutant input into streams by reducing contamination in the overflowing water. This technology thus focusses on water quality. The demonstration case study on the lamella settler in the Emscher region is reported in chapter 2 of this deliverable.

1.2.2. Real Time Control of sewer network

The RTC is a solution aiming at optimal utilization of the entire underground storage volume available by implementation of the ADESBA communication software. The aim is to reduce pollutant input into streams by reducing the overflow frequency and volume from CSOs into streams. Thus, the focus is on water volume. Based on minute-by-minute information on the inflows and outflows of every storage reservoir as well as on the combined sewer overflow and water level, the water level in all storage basins is equaled. The demonstration case study on the RTC in the Emscher region is reported in chapter 4 of this deliverable.

2. Task 31.1 – Decentralized CSO treatment

2.1. Task description

Task 31.1 – Decentralized water treatment (M1-M42, EG, UFT, UDE)

The development in T21.1 provided the necessary information for the design of lamella settling modules that were implemented in a CSO in the Emscher catchment operated by EG within WP31. The demonstration of this solution at the Emscher demo site in WP31 consisted of the following tasks:

- Preparation for the full-scale demonstration in WP31. Definition of criteria for suitable demonstration sites and selection of a suitable prototype structure as a demonstration site. At this site, an experimental cross-flow lamella settler unit located in a movable container will be installed temporarily. The same unit will be used afterwards in the Hoffselva demo site. The mode of operation (feeding by pumps only during rain inflow) is to be fixed with respect to the data of the site. The site requires electrical power supply and the structure should allow the use of a mobile submergible pump. Data on the CSO tank operation and its catchment area should be well documented.
- Conception and CAD design of an experimental cross-flow lamella settler for use on the demo site (UFT); Numerical simulation to optimize design for smooth parallel through flow (UDE).
- Construction of the unit as a mobile container. Installation at a suitable CSO tank, experimental rigging (electrical controls for pump and data recording equipment) (UFT).
- Installation of the prototype unit (UFT), operation of the unit (EG) and sampling for monitoring of the sedimentation efficiency during a sufficiently long time interval, *e.g.* one year (UDE); Compilation and documentation of results (EG, UDE).
- Establishment and calibration of a “small” prediction model which allows determining the performance also of other sites where CSO tanks are to be retrofitted (decision support) and allows also the sizing and design of cross-flow lamella settlers for this application. Since there are already lots of simulation models on the market, it is not intended to create special sophisticated software, but *e.g.* an Excel VBA tool for use to evaluate output data (high-resolution flow hydrographs) of commercial quantity-quality simulation models (UFT, UDE, EG).

2.2. Aim of the solution

Lamella settlers can be used to increase the sedimentation efficiency of particle-rich fluids. Within DESSIN, a new type of lamella settler – the cross-flow settler – was developed and tested.

Lamella settlers are tried-and-tested sedimentation devices in process technology (*e.g.* mining, quarries, etc.). The principle is used in many commercial devices. The basic idea is to feed the sediment-laden flow through narrow gaps between plates in order to provide a merely small settling distance of some centimeters, rather than of the whole depth of a settling tank. Lamellae also increase the effective area of the settler and thereby reduce the surface load. This can increase the settling efficiency. Plate or honeycomb arrays made from plastics or other materials are produced in a variety of dimensions and shapes from different manufacturers.

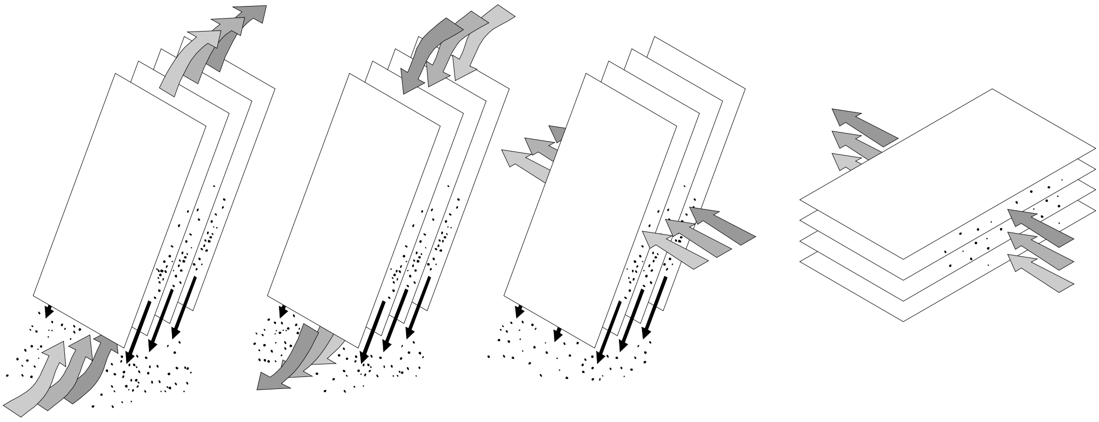


Figure 2 Upflow, downflow, cross-flow and horizontal plate settlers (from left to right) (Weiss2014).

Figure 2 shows basic arrangements for lamella settlers made from plate arrays. Except for the horizontal plate settler, the plates are inclined to allow the settled sludge to slide down into a sludge sump from where it can be removed. Most popular are upflow settlers. In this arrangement, also honeycomb profiles or tube arrays are used. Cross-flow settlers are used less frequently. They are made from plates, either flat or corrugated. Their advantage is that sediments which are sliding down laterally do not mix with the inflow, an effect which has been observed with upflow settlers in model tests. In DESSIN, cross-flow plate settlers were investigated.

The lamella settler technique (of any type from Figure 2) has been applied in the past years in several research and demonstration projects for treatment of stormwater in separate drainage systems as well as for treatment of combined sewage, *e.g.* overflow from CSO tanks. The latter field of application is the focus in DESSIN. Literature on the subject has been discussed in the DESSIN model test report (D21.1, Weiss 2017). In the cited projects, CSO tanks were equipped with lamella separators of various sizes which were passed through by combined sewage. In most structures, integral (non-movable) upflow settlers were used. It is of importance how to clean the lamellae since, particularly in combined sewage applications, as considerable accumulation of sludge and sewage garbage may occur. For this reason, the DESSIN lamella settler is equipped with a special cleaning mechanism.

The literature does not yet provide much information on the settling performance of lamella settlers in combined sewage treatment. Kemper *et al.* (2014) tested an upflow settler which was also built by the DESSIN project partner UFT. The unit was a similar test container as the DESSIN container and was operated in a similar mode. It was located at the primary treatment of a wastewater treatment plant and was fed with combined sewage during storm events. The results of this investigation were quite encouraging, since they showed good settling efficiencies even for the TSS fine fractions (fraction of TSS < 63 µm). An efficiency of approximately 45 % at a steady surficial loading of 4 m/h was observed, as shown by the blue data points in Figure 3.

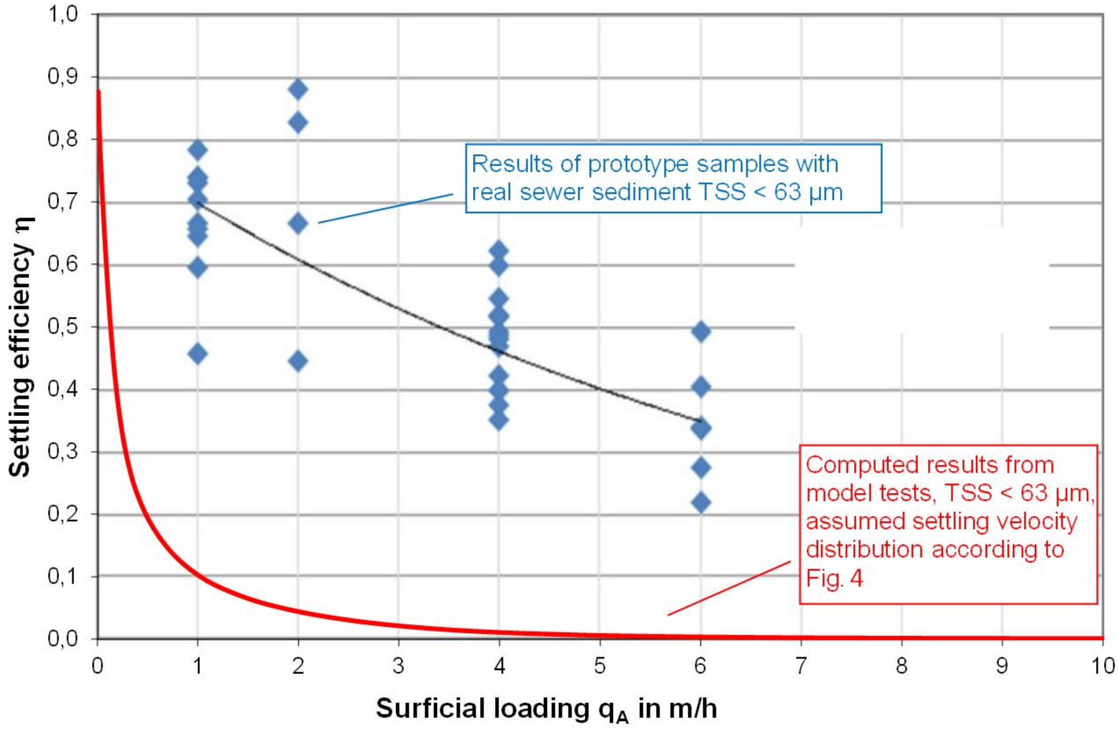
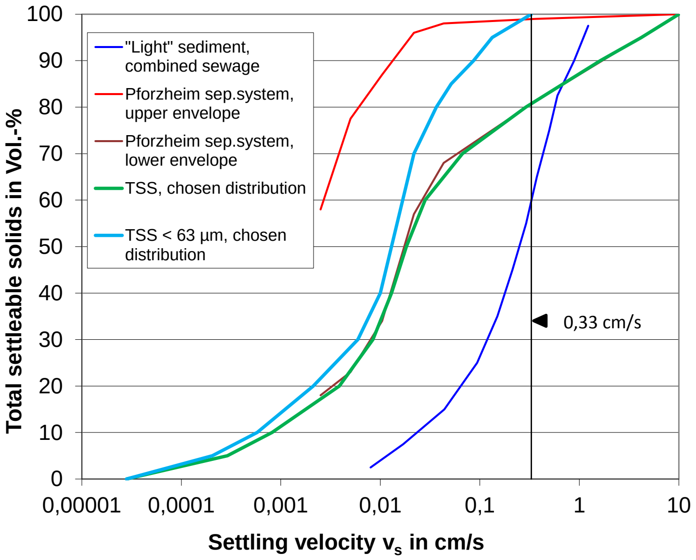


Figure 3 Comparison of measured settling efficiencies of real sewer sediment (TSS < 63 µm) to computed values from model tests (Weiss 2016).

Similar to the present project, model tests with plastic beads were conducted prior to prototype testing with real sediment. Weiss (2016) compared the efficiency curves, which were scaled up from the model tests to the prototype results, according to the formula:

Settling efficiency = f(surficial loading / settling velocity)

The background for this evaluation is the settling theory according to the Hazen formula. For more information see D21.1 (Weiss 2017). The assumption for the unknown distribution of settling velocity for the real sewer sediment is strongly shaping the result, see Figure 4. The comparison between model tests and tests with real sewage sediment showed very poor coherence (Figure 3). This emphasizes the strong influence of the nature of the sediment.



Settling velocity distribution, TSS < 63 µm		
Fraction i	Percent of sample α_i in %	Mean settling velocity $v_{s,i}$ in cm/s
95-100	5	0,23168
90-95	5	0,10997
80-90	10	0,06156
70-80	10	0,02913
60-70	10	0,01927
50-60	10	0,01487
40-50	10	0,01148
30-40	10	0,00798
20-30	10	0,00404
10-20	10	0,00135
5-10	5	0,00039
0-5	5	0,00012

Figure 4 Distribution of settling velocity for different types of sediment and for TSS fine fractions in surface runoff of separate systems (Weiss 2016).

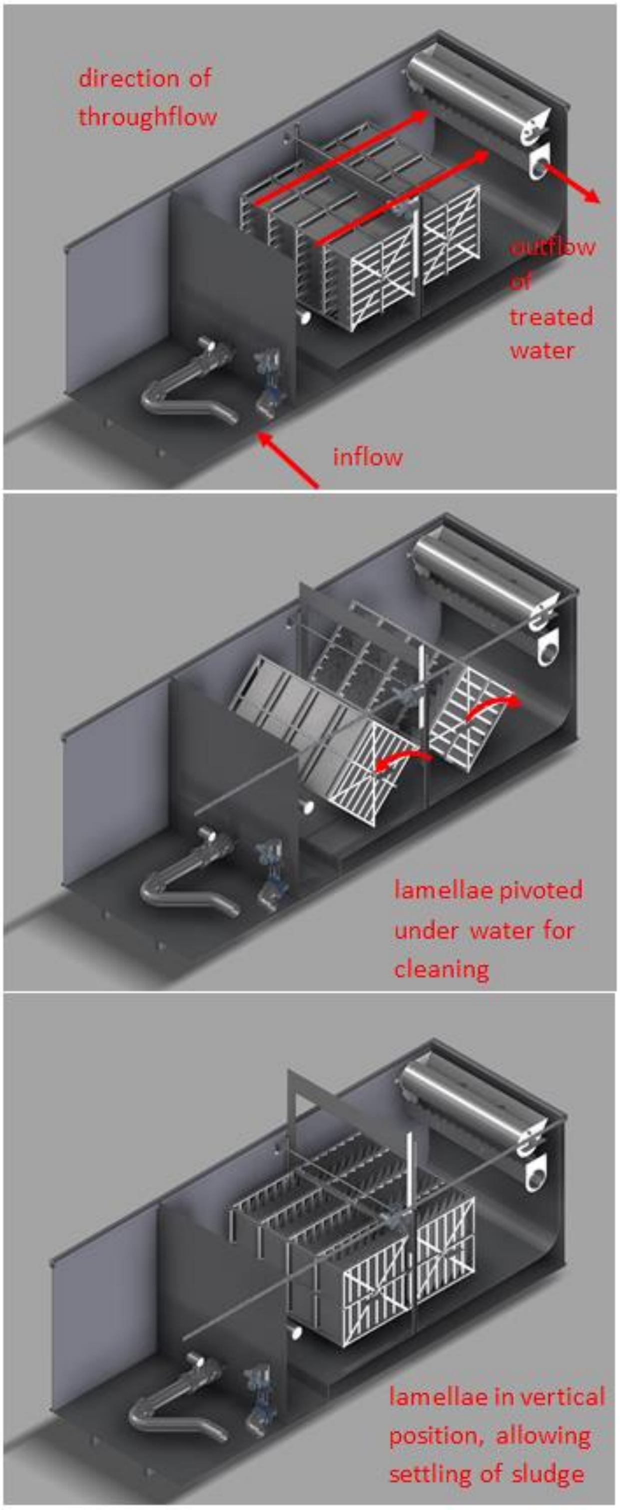
The lesson learned from the investigation of Kemper *et al.* (2014), albeit on another type of lamella settler, was that the overall efficiency is obviously not only determined by the settling process but also by the fate of already settled sediment. The following effects were expected:

- The well-rolling plastic beads slid down the 60° inclined upflow settler surfaces easily and immediately remixed with the inflow, while "real" sewage sediment behaves more "sticky" and binds to the lamella surfaces until it forms a heavy layer sliding down in "plaques" which will not immediately disintegrate and remix with the inflow.
- The sediment properties influence the process even more. If we assume that the real sewage sediment at the treatment plant trends to spontaneous flocculation (which can be observed under certain conditions), the fine fractions will form larger easy-to-settle flocs. However, during preparation of the taken samples by wet sieving, these flocs disintegrate again and the material is classified as "very fine", misleadingly demonstrating a good settling efficiency for even the finest fractions.
- Finally it is also essential that the flow through the lamellae is parallel, which may be difficult to obtain with upflow settlers.

2.3. Description of the demo case

2.3.1. Elements and functions of the cross-flow lamella settler container

A 3D graphic of the cross-flow lamella test container is shown in Figure 5.



The container is a standard roll-off container with a bulkhead added to form a vessel. The vessel is lined with polyethylene; all structures inside are made from stainless steel. The inflow is measured by a magnetic flowmeter (MFM) and distributed by a T-shaped manifold pipe. Water flows mainly in horizontal direction through two cubic lamella modules. The lamellae are made from stainless steel sheets and are roof-shaped in order to allow sliding down of settled sludge to both sides, minimizing entrainment into the main flow.

The overflow is collected on the opposite side by an open U-shaped flume. Via the flume, the overflowing water exits the container laterally.

After a certain duration of operation, accumulation of sludge must be expected on the lamellae. In order to enforce sliding down of this sludge, a pivoting mechanism is used which pivots both modules while the container is still water-filled and the modules are still immersed. The sludge layer is loosened by the swaying motion. Then, the lamellae are pivoted in vertical position and the sludge may settle down to the bottom of the container.

Finally the container is emptied via a motor-driven emptying valve into an outflow. In a last step, a tipping flusher is filled with clean water and cleans the dry-fallen bottom by a flushing wave.

Figure 5 a-c 3D-visualization of the DESSIN test container with two cross-flow lamella settler modules.

Elements in the container (Figure 6):

Inside of the container:

- Inflow pipe with MFM
- T-shaped pipe manifold, exchangeable
- 2 cross-flow lamella modules with pivoting mechanism (an electric rack-and-pinion drive, sliding a frame up and down which is acting as underflow protection; both modules are hinged to this frame and are carried by short lateral rails so they are pivoting about 90° as the frame moves up and down)
- U-shaped overflow flume with notched overflow edges
- Tipping flusher for rinsing of the empty container
- Emptying pipe with motor valve
- Water level probe for continuous measuring of the water level in the container
- Electrical cabinet with controls and data logger

Outside of the container:

- Main feeding pump (at Emscher demo site located in a sump of the pumping station of a CSO tank)
- Water level sensor for measuring the water level in this sump
- Feeding pump for tipping buckets (for rinsing after emptying)
- Small container for rinsing water (1 m³)

The sensors more in detail:

- MFM DN (diameter) 150 in the inlet pipe (measures inflow to the lamella settler)
- Submersible probe 0-4 m range, inside the container (measures water level)
- Proximity switch for tipping bucket (is triggered when the flusher has tipped)
- In the pump sump: Submersible probe 0-10 m range (measures water level)

The container cabinet (Figure 6) contains the entire electrical system (including a frequency converter for the feeding pump). It is connected via cable to a 400 V three-phase AC socket.

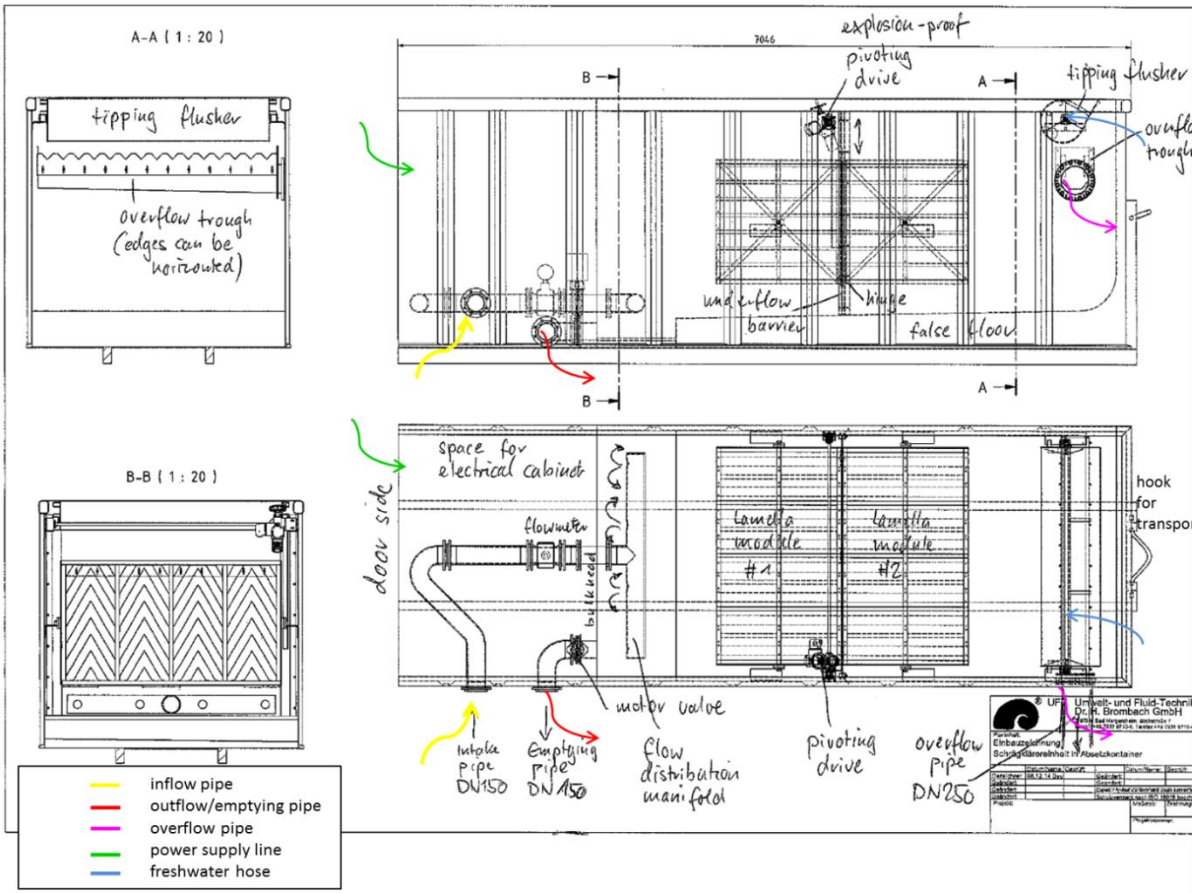


Figure 6 Scheme of lamella settler container solution, consisting of the electrical cabinet and the water-filled main cabinet, with incoming and outgoing pipes indicated in colors.

Functions in automatic mode:

1. Standby position (waiting for a rain event): lamella modules in the working position, feeding pump, tipping bucket pump off, emptying valve closed.

2. Rain begins: When the water level in the sump exceeds a given threshold, the feeding pump is turned on. The pump operates at a constant, pre-selectable (on the touch screen of the programmable logic controller (PLC) located in the electric cabinet) flow which is measured by the MFM. It is possible to run experiments with different yet constant flow rates and surface loadings. There is no inflow valve, thus, the pump has a check valve to prevent drainage of the container by backflow when the pump is turned off.

3. Rain ends: If the water level drops below the threshold, the feeding pump turns off.

4. If the feeding pump is off and the water level inside the container is higher than the lower end of the lamellae, the lamellae are probably dirty and need to be flushed, therefore, a full flushing cycle starts: The pivot mechanism pivots the lamellae up and down a few times (Figure 7,

adjustable in the PLC). The surge motion of the water will loosen any sludge adherent to the lamellae. This movement is finally stopped when both modules are in vertical position; the loosened sludge will sink down to the tank bottom. Adjustable pause (some seconds).

5. Start of discharge cycle: Opening of outflow valve; the container is emptied by gravity. When the water level in the container is almost zero and the bottom has fallen dry, the filling pump of the tipping flusher is turned on; the flusher will automatically tip when completely filled. The tipping event is registered by a proximity switch. If this has happened, the filling pump is stopped. Adjustable pause (some seconds).

6. If feeding pump stops and the water level in the container is still lower than the lower end of the lamellae (resulting from a short or feeble rain event): Only the discharge cycle and flushing mode are performed as described above.

7. For tests without lamella modules, the modules are removed from the container and the pivot mechanisms are turned off. The process is run as described above.

8. At Emscher demonstration site it is possible to start the container operation at any time, if a low water level threshold in the feed pump sump is selected or if the pump sump is filled by turning of the CSO pumps. The water level threshold of the feed pump can be changed in the software.

Figure 7 Self-cleaning process (here with clean water).

Functions for data recording and transfer:

The implemented data recording devices were a data logger and a remote control station.

The data logger records the flow and water level values measured by the sensors (MID and two submersible probes) as hydrographs on an SD card or at site with an interface to the laptop. To collect and save the data, somebody must regularly visit the container site. Remote control station and UFT server: The data are real-time transmitted to the UFT server. UDE has remote access and can access the data in real time. Alarm functions are possible (e.g. rising water level alarm to mobile phone). The measured inflow (MID signal) is accessible from outside to allow interface with the sampling device. This allows sampling proportionally to inflow.

2.4. Implementation process

2.4.1. Planning

Requirements for a suitable test area:

- The test container has outside dimensions of 7 x 2.5 m (length x width) and a total weight of 40 t when filled with water (around 7 t empty). For transport and installation of the container, a paved area and enough space for access, e.g. for the pickup truck, are required.
- Different sites and ways of operation are possible:
    - o at a CSO with combined sewage water from the overflow
    - o at a CSO with dry weather discharge from the overflow or combined sewage water from the sedimentation basin
    - o at a WWTP with dry weather discharge from the primary sedimentation basin

Using dry weather discharge has the advantage that tests can be run independent of rain events. It has to be noted, however, that in this case the concentration and type of solids may be different than under a CSO event.

- Provision of three-phase current 400 V for the pump, which needs approximately 7.5 kW. The container contains an electronics board from which the pump and other electrical devices can be controlled.

Selection of a suitable test area:

The CSO Ohmstraße was identified as a suitable test site, as it fulfilled the above mentioned requirements: enough space was available for the container but also for its transport and installation, access to combined sewage was possible, electricity and freshwater could be provided, and the site was well accessible to EG staff and UDE.

2.4.2. Numerical simulation

Conception and CAD design:

The test container was designed by UFT. The concept was based on a design of the container used for the testing of counter flow lamellae by Kemper et al. (2014). The design was adapted to the requirements of cross-flow lamellae. The CAD drawings were prepared by UFT for construction purposes and handed over to UDE for preparation of the numerical modelling.

Numerical simulation: Verification of inlet-structure

To verify the planned design of the container, and in this context especially the inlet structure, a simplified model of the container was used to identify flow velocity patterns. The analysis was done using the software ANSYS Fluent. Using a simplified model, four different inlet structures were tested at three different discharges. The main aim was to identify the inlet structure that results in the most even flow velocity distribution at the lamella modules. However the simulations did not include the lamella modules.
The four structures simulated were (Figure 8):

- No disturbance structure
- Deflector plate
- T-shaped manifold with four backwards directed outlets (at the bottom of container)
- T-shaped manifold with four backwards directed outlets (at the middle height of container)

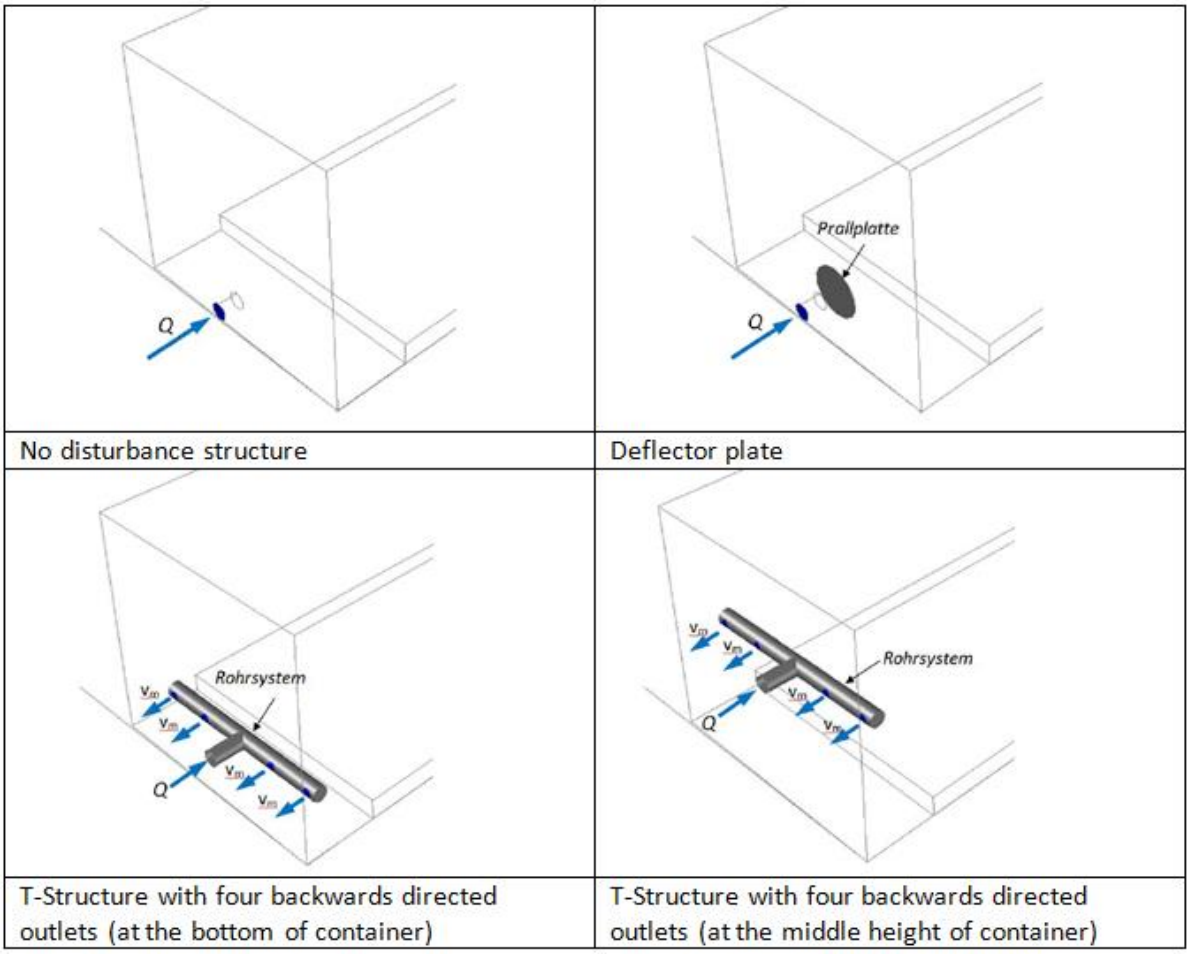


Figure 8 Different types of inlet structures to the test container.

Flow velocity distribution was analyzed using discharges of 30, 36 and 42 l/s. The discharge of 42 l/s is the maximum discharge which the pump could generate under real-life condition. Profile sections of the container at the intended place of the lamella modules were analyzed to compare velocity patterns of the four different structures.

Figure 9 shows simulated discharge at sections of the container with the four different inlet structures from the side and cross sections at location of the lamella modules. The example shows the velocity distribution at a discharge of 36 l/s.

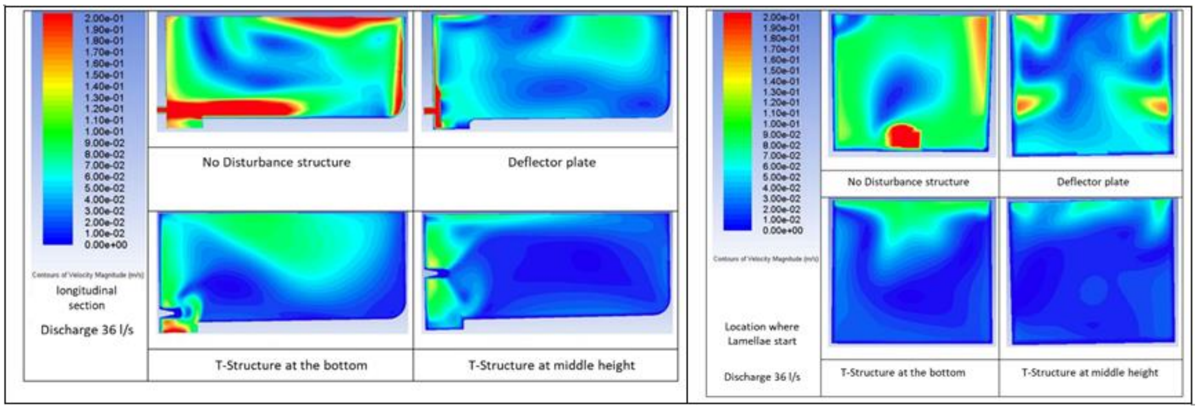


Figure 9 Modeled velocity distribution profiles inside the container at a discharge of 36 l/s. Left: Side view; Right: Cross section at beginning of lamella package.

The numerical simulations confirmed that a T-structure as inlet at middle height of the container was the best option (Figure 9, lower right position of the left and right side). The flow velocities for each of the different discharges show the most even distribution using this type of inlet structure, especially at the location where the lamella modules are to be placed.

These numerical tests focused on the flow conditions caused by the inlet structure. The tests did not show the influence that lamellae would have on the particles inside the water. However, the flow conditions indicated that with the chosen inlet structure the backflow was minimized. This contributes to the efficiency of the lamellae due to a more equalized flow where fewer sedimentated particles are remobilized. It is expected that in reality the backflow could even be lower compared to the backflow observed in the simulation due to insertion of the lamellae. This can help to align the flow in a more horizontal and parallel direction, preventing backflow.

2.4.3. Technical preparations and implementation

Construction of the unit

After detailed CAD design was completed at UFT's design and construction department, the container was assembled and equipped with all components at the UFT shop in Bad Mergentheim, Southern Germany. It was christened "Claire II". After thorough function tests of all parts, the container was transported to the Emscher demo site using a container roll-on pickup truck. No crane was needed for placing the container at the foreseen position at the Ohmstraße CSO tank.

Operation setup and installation

The container is located next to the CSO tank Castrop-Rauxel Ohmstraße. During storm events the water level in the shaft of the pumping station (pump sump) starts rising. When it reaches the already mentioned, initially chosen threshold level, the container pump inside the pump sump will switch on automatically. The combined wastewater is then pumped into the container. After filling up the container volume, the water will pass the lamellae. It leaves the container by the overflow flume and is fed finally via a discharge pipe back into the sewer again (downstream of the CSO tank). In the course of the DESSIN project, it was not allowed to discharge the lamella-treated water into the river.

The container was installed by EG staff, UFT, UDE, and external contractors. The installation process is depicted in Figure 10 to Figure 23. A few on-site adjustments were made.

Figure 10 Container delivered to study site CSO facility "Regenüberlaufbecken Ohmstraße" in Castrop-Rauxel.

Figure 11 Installation of the pump in the CSO pump sump.

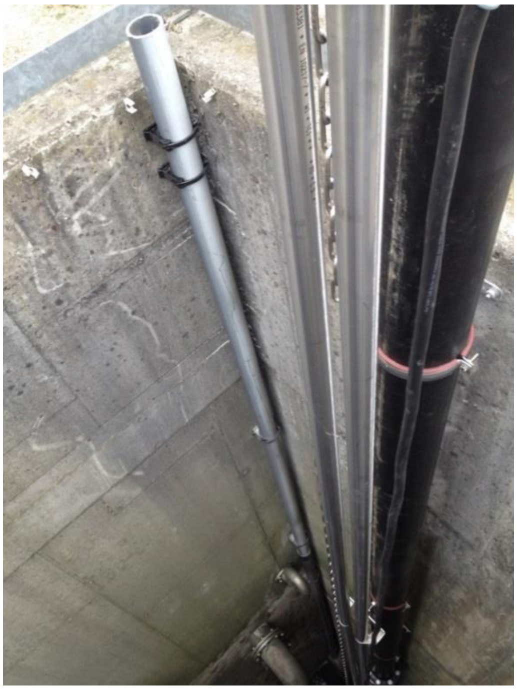


Figure 12 Installation of the protection pipe for the pump's level sensor.

Figure 13 Installation of the inflow pipe from the pump to the container.

Figure 14 Installed inflow pipe and hose from the pump to the container.

Figure 15 Required reinforcement of the attachment of the inflow pipe.

Figure 16 Attachment of the discharge pipe to the container, discharging into the next sewer.

Figure 17 Construction works of the underground discharge pipe directing the treated water to the next sewer.

Figure 18 Attachment of a flexible emptying pipe, discharging back into the pump sump.

Figure 19 Optimization: Replacement of the flexible by a hard plastic emptying pipe connected to the discharge pipe, discharging into the next sewer.

Figure 20 Installation of a fresh water tank feeding the container's self-cleaning mechanism after every container operation.

Figure 21 Provision of electricity for the container operation from the CSO building.

Figure 22 Electric cabinet for automated container control.

Figure 23 Final setup of the container at CSO Ohmstraße.

Sampling strategy and parameters

The project aim was to investigate the efficiency of the lamella settler, which treats combined sewage during rain events. This investigation included both flow and load measurements at the inflow and overflow. For the measurements of the inflow and overflow pollutant concentrations, two different systems were used.

The first measurement system consisted of two spectrometer probes of the company s::can. The two sensors were used to measure pollutant concentration in the inflow and overflow (see Figure 24 to Figure 26). The method is based on the correlation between adsorption of different wavelengths and various sewage pollutant parameters. The spectrometer probes recorded four parameters every 15 seconds. This enabled an almost continuous online load recording. A connected air pressure system was used to clean the sensor every 3 minutes by releasing pressurized air against the sensors. The sample taking devices were controlled via a Siemens Logo PLC system. This system was connected to the control system of the container, which reported the water level inside the container. The sampling started automatically when the water level inside the container reached a certain level and ended when the water level dropped below this level.
The position of the probes and sensors had to be re-adjusted from the left to the right side of the container (viewed in flow direction). The reason for this was an uneven flow with a higher flow velocity on the left side of the container, which was detected via a Fluorescein test (see chapter 2.5.1).

These continuous measurements were supplemented by an automated collection of wastewater samples which were subsequently analyzed in the laboratory. At the inflow and the overflow, tubes were installed that were connected to two automatic samplers (Figure 24). These devices were placed into the container's electrical cabinet (Figure 27). The samples were taken on a time-proportional basis with given time intervals between samples. However, the intervals could also be altered in the course of a rain event (*e.g.* shorter intervals at the beginning of an event, allowing to better describe the characteristics of the first flush). To avoid degradation of the contaminants during storage, the samples were cooled until analysis.

The results of the analysis were also used for calibrating the photometric sensors. If the accuracy of the photometric measurements was high, the frequency of the additional sampling could be reduced or sampling could be discontinued.

Characteristics of the automated sampler:

- Endress + Hauser ASP station D2
- Sampling in 24 1-liter bottles
- Cooling of the samples at 7 ° C
- In the beginning of each event, two samples with a five minutes interval were taken and later on in ten minutes intervals.

Parameters to be assessed in the laboratory analyses:

- Filterable substances and fine-grained filterable substances (Total suspended solids (TSS)), fine TSS < 63 µm)
- Chemical oxygen demand (COD)
- Total organic carbon (TOC)

Parameters assessed by the s::can probe online measurement every 15 seconds:

- Dissolved organic carbon (DOC) and TOC

or

- COD and
- TSS

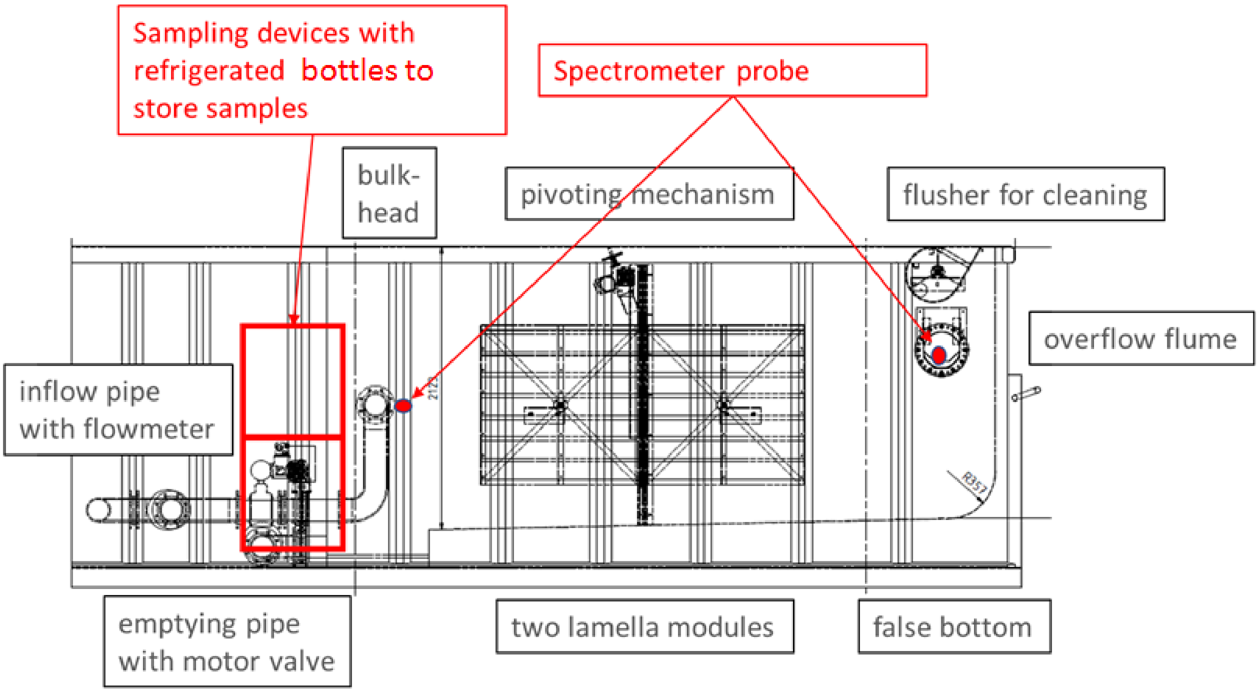


Figure 24 Position of sampling devices inside container.

Figure 25 Installation of s::can control unit in the electric cabinet.

Figure 26 Installation of s::can probes at in- and overflow.

Figure 27 Installation of automatic sampler in the electric cabinet.

Additionally, the inflow is measured by a magnetic-inductive flowmeter. Under constant hydraulic conditions, the inflow volume corresponds to the overflow volume and the overflow in l/s equals the inflow in l/s when the container is full of water. Therefore, no additional hydraulic measurements at the overflow are needed. The filling process of the container is monitored by a water level gauge (pressure sensor) with a range of 0-4 m.

Approval by agency

Operating the container required the approval by the district council in charge of CSO Ohmstraße. The test phase was approved under the premise of complying with two obligations: First, the combined sewage treated by the container was not allowed to be discharged into the next stream (via the ditch behind the container, as can be seen in Figure 28). Instead, the water treated by the container had to be deviated back into the next sewer (Figure 16 and Figure 17). This obligation was legitimate, as the treatment efficiency of the container was not known before the test phase and the introduction of possibly insufficiently treated water into the freshly restored Emscher tributary was not acceptable.

Secondly, a standard report on the operation of the CSO (which is usually handed in to the district council each June), had to be handed in after the end of the test phase. This was to show that no higher overflow activity of the CSO facility occurred.

2.5. Operation

The container's setup at the pumping station of CSO Ohmstraße in Castrop-Rauxel was completed in summer 2015 and tests were conducted until May 2016, when the container was shipped to Norway.

Inflow water was pumped from the pump sump into the container. Water flowed through the lamellae and exits the container via the discharge pipe.

Figure 28 Container in action, located at CSO Ohmstraße in Castrop-Rauxel.

2.5.1. Test runs

During the first test runs, relatively low TSS concentrations in the incoming combined wastewater were detected (mean TSS concentrations of less than 50 mg/l). This might be caused by groundwater infiltration into the combined sewer. Since these low concentrations are not typical for combined sewage and results would not have been transferable, the subsequent tests were conducted using dry weather discharge in order to assess effects at higher particle concentrations. The pollutant concentration of the sewage during dry weather at this site seemed more comparable to typical combined sewage pollutant concentrations. For tests during dry weather, sewage had to be pumped from the pump sump into the container. For the water-level triggered container pump inside the pump sump to start automatically, the CSO pumps had to first be stopped a few hours before container operation in order to let the water level inside the sump rise. They were then turned on briefly to mix well the sewage before it was pumped into the container.

After this adjustment, 13 samplings with dry weather and 1 additional sampling during a rain event were conducted and monitored (Table 1).

Table 1 Dates and flow rates of container test runs with lamellae.

Inflow rate	Samplings with lamellae					
10 l/s	17.02.2016	04.03.2016 (Storm water)	09.03.2016	14.03.2016	19.04.2016	21.04.2016
15 l/s	18.03.2016	21.03.2016	15.04.2016	20.04.2016		
20 l/s	07.04.2016	18.04.2016				
25 l/s	12.04.2016	29.04.2016				

It is to be noted that the tested flows are lower than the typical design criteria for lamella settlers in CSOs which is 4 m/h (persona communication, Weiss 2016).

To assess the sedimentation effect caused by the lamellae, four tests without the lamella modules were conducted (Table 2). In these four cases, sedimentation was only provided by the container volume.

Table 2 Dates and flow rates of container test runs without lamellae.

Inflow rate	Samplings without lamellae	
10 l/s	03.05.2016	04.05.2016
15 l/s	06.05.2016	
20 l/s	11.05.2016	

2.6. Results and discussion of test operation

2.6.1. Fluorescein tracer tests

To detect the hydraulic retention time inside the container, a tracer experiment with Fluorescein was conducted (Figure 29). With the knowledge of the retention time, the difference between inflow and overflow could be time-adjusted. It was also used for calibration of the hydraulic model. Thanks to the high visibility of the Fluorescein tracer, the test could also be filmed from a bird view perspective to obtain information about the flow distribution. To monitor the Fluorescein tracer, a camera was installed above the container. The tracer was introduced into the pump sump and mixed with the sewage water. It was then pumped into the container by the container pump. Samples at the inlet and overflow were taken every minute. Samples were analyzed by using an UV-Vis spectrometer, measuring the absorption at the wave length of 485 nm. Tests have been conducted at flow rates of 10 and 15 l/s.

The recorded video of the tracer test showed a current bypassing the lamella modules on the left side (in flow direction) (Figure 29). As the sample taking device and spectrometer probe had been installed inside the spillway on the left side, an adjustment had to be conducted in order to not measure water which had not passed the lamellae: The devices were, thus, moved to right side.

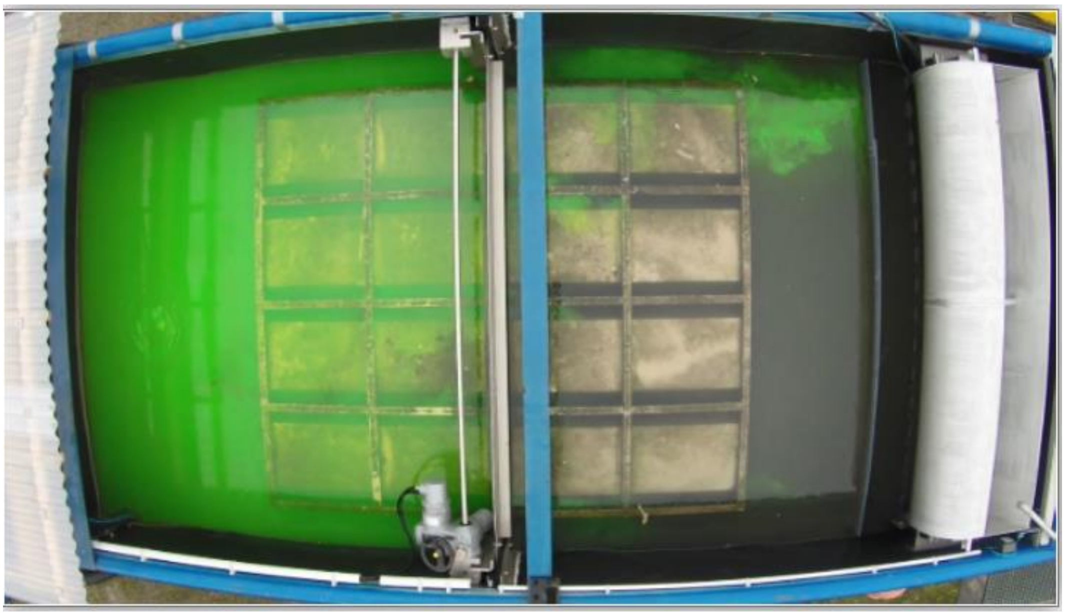


Figure 29 Aerial view of the container during the fluorescein tracer test. Flow direction is from left to right. A current bypassing the lamella modules on the left side was observed.

The hydraulic retention time was found to be 13 minutes at a discharge of 10 l/s (Figure 30). This means that overflow measurements correspond to inflow measurements 13 minutes before, which should be considered during data evaluation. Tracer tests with discharges of 15 l/s were also conducted and detected retentions times of 9 minutes.

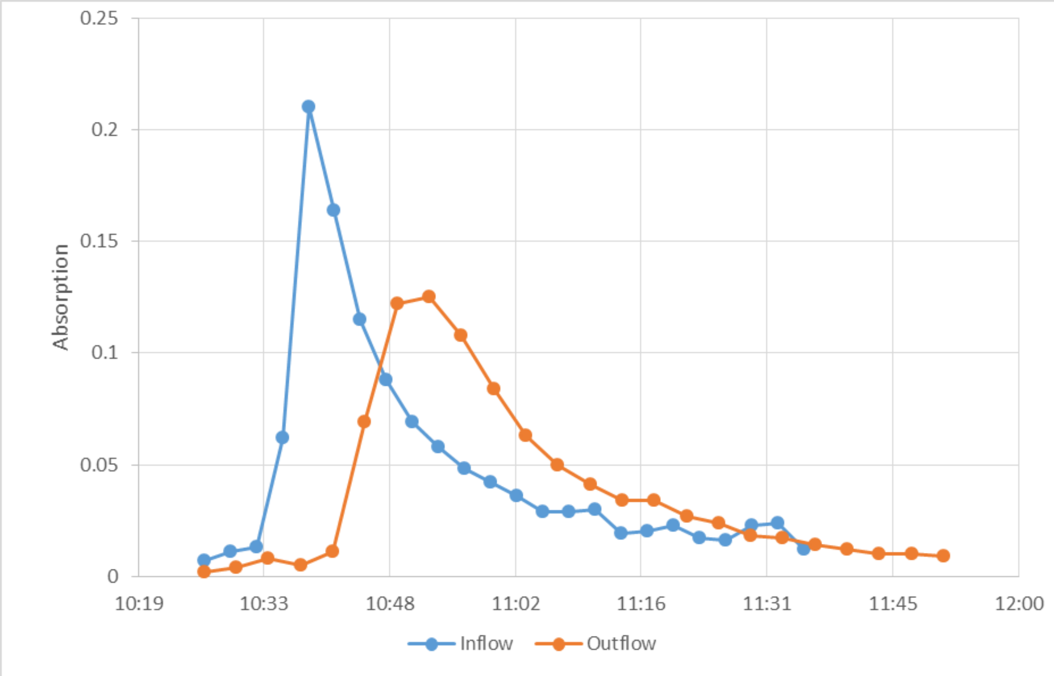


Figure 30 Results of one Fluorescein tracer test at a discharge of 10 l/s. The lag time identified between the inflow and overflow peak is 13 minutes.

2.6.2. Settling velocity distribution

To support the interpretation of the test results, the tested wastewater was analyzed with regard to the settling behavior of the particles it contains, *i.e.* the TSS. Therefore, three samples from the pump sump were taken and the settling velocity distribution was analyzed.

Figure 31 shows the mean settling velocity distribution of the three analyzed samples in comparison to settling velocities of combined sewage sediments reported in literature (Weiss and Michelbach 1996). The samples revealed a medium to poor sedimentation behavior. This measured settling velocity denotes total TSS. The ratio and concentration of the fine TSS fractions were not analyzed separately.

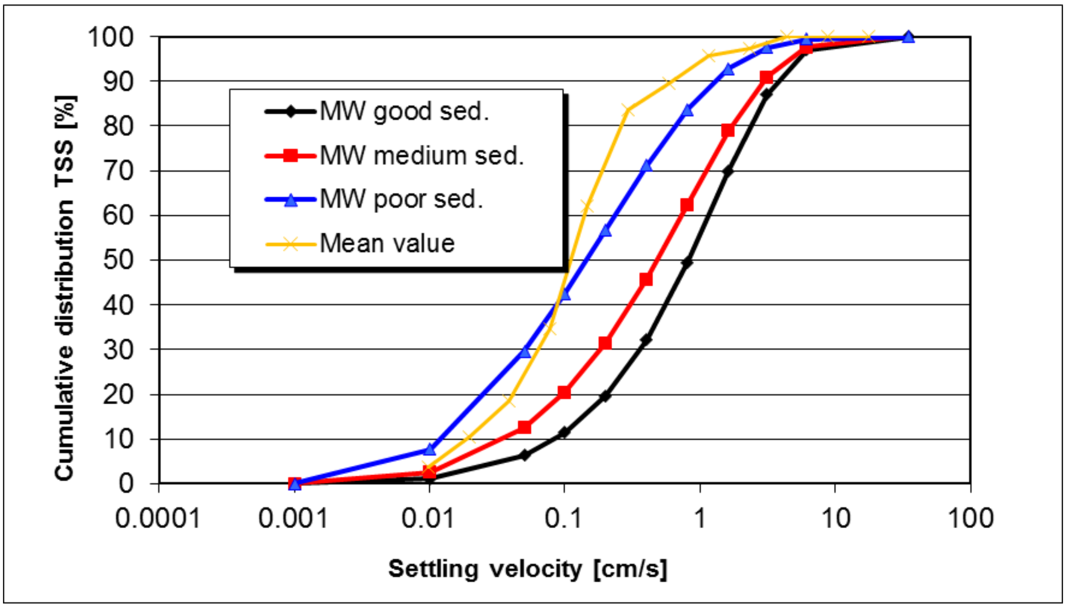


Figure 31 Mean settling velocity of sediments in three dry weather sample (yellow) in comparison to literature results of combined sewage samples with poor (blue), medium (red) and good (black) sedimentation behaviour.

2.6.3. Comparison of lab results and spectrometer probe results

The results of the s::can probes were calibrated and validated with the results obtained from the automated samplers.

The concentrations detected by the s::can spectrometer probes were closely correlated with those determined in the laboratory results at some of the sampling events (Figure 32). At other events, they had the same trend and gradients but did not match quantitatively (Figure 33). Results were, therefore, used to qualitatively compare in- and overflow-concentrations. The spectrometer probes had a relatively high demand for service during operation because the cleaning mechanism failed several times. Manual cleaning was therefore required before every test. In general, the s::can probes measured lower concentrations than the lab results. Best matchings of lab results and s::can results were observed at low concentrations (approximately < 100 mg/l). This limited the evaluation in some dry weather tests.

The s::can results were also used for the verification of the residence time using the Fluorescein tracer. Time shifted concentration peaks in the inflow and overflow could be detected confirming the tracer tests.

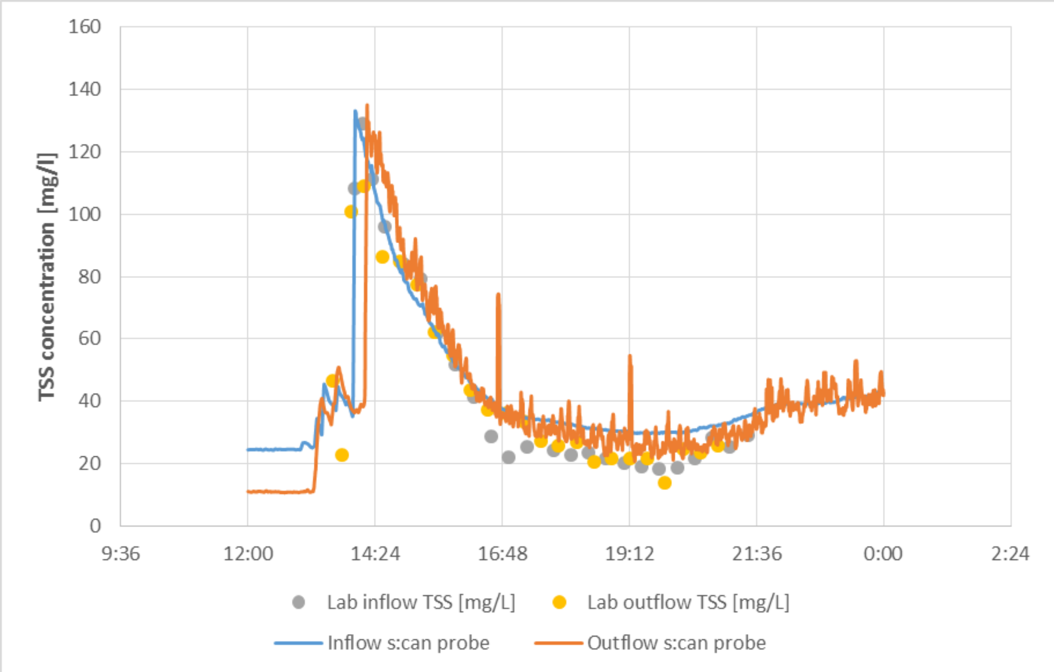


Figure 32 Comparison of TSS concentrations recorded with s::can probes (blue, orange) with those analyzed in the laboratory (grey, yellow).

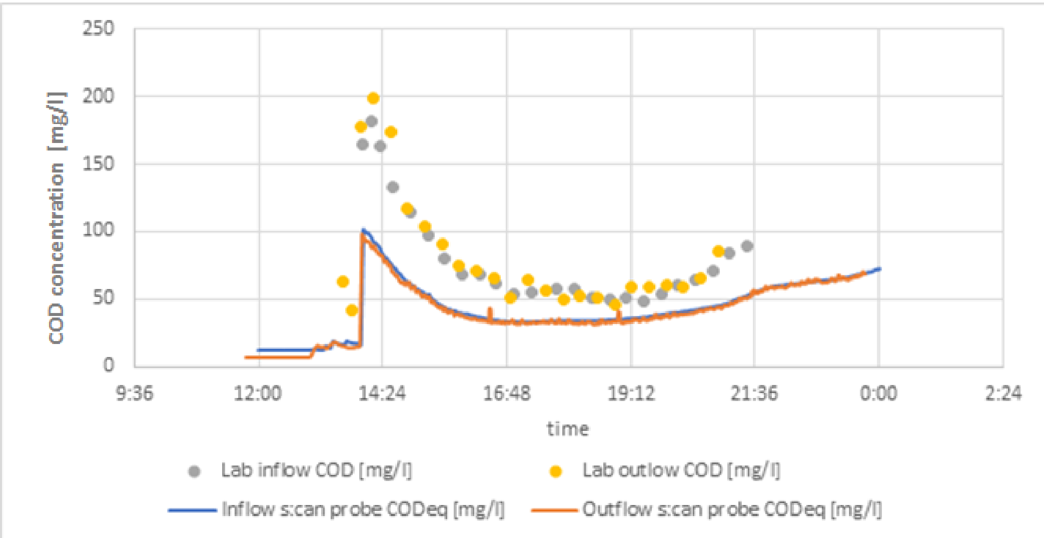


Figure 33 Comparison of COD concentration recorded with s::can probes (blue, orange) with those analyzed in the laboratory (grey, yellow).

2.6.4. Effect on metals

At two events (dry weather and rain event), samples were taken at the inflow point and tested for heavy metals using X-Ray spectroscopy (AnalytiCON instruments XL2 980). However, the observed concentrations were below the limit of detection at this specific CSO site, , and thus, heavy metal monitoring was not continued.

2.6.5. In- and overflow concentrations

The inflow and overflow concentrations of the four parameters TSS, fine TSS, COD and TOC were determined for the 13 test runs conducted during dry weather (Table 1) and are depicted for selected events in Figure 34 to 37 for TSS, fine TSS, COD and TOC, respectively.

Figure 34 to 37 show typical concentration curves: the concentrations are declining with time and in- and overflow concentrations are converging. For the fine TSS fraction, the concentrations behave in another way at this specific sampling (Figure 35).

It can also be seen that peak concentrations only occur in the inflow. This indicates that peak concentrations are being reduced by the lamella settler.

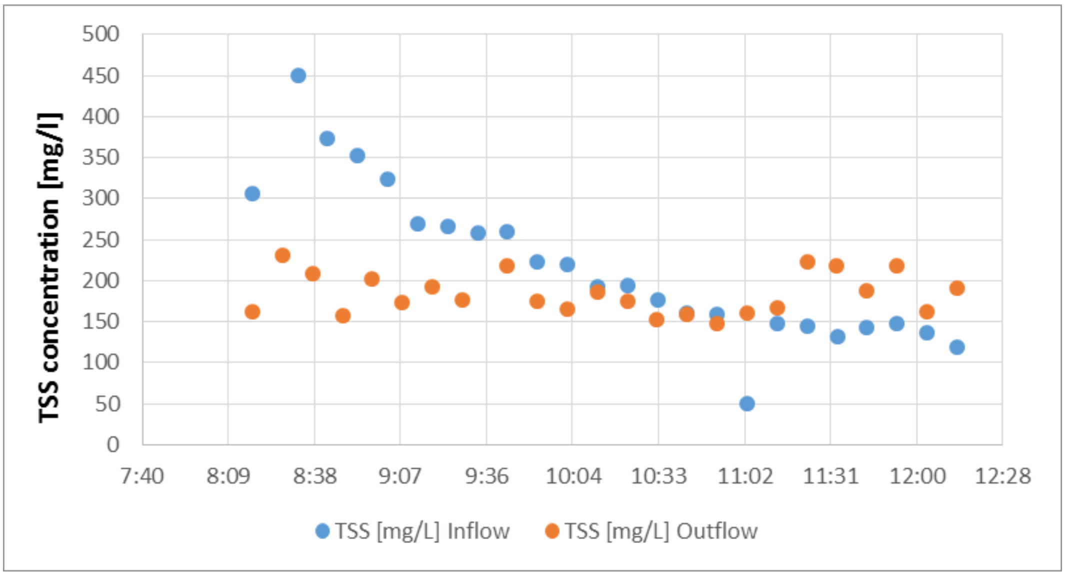


Figure 34 TSS concentration during an exemplary dry weather test with a flow of 10 l/s.

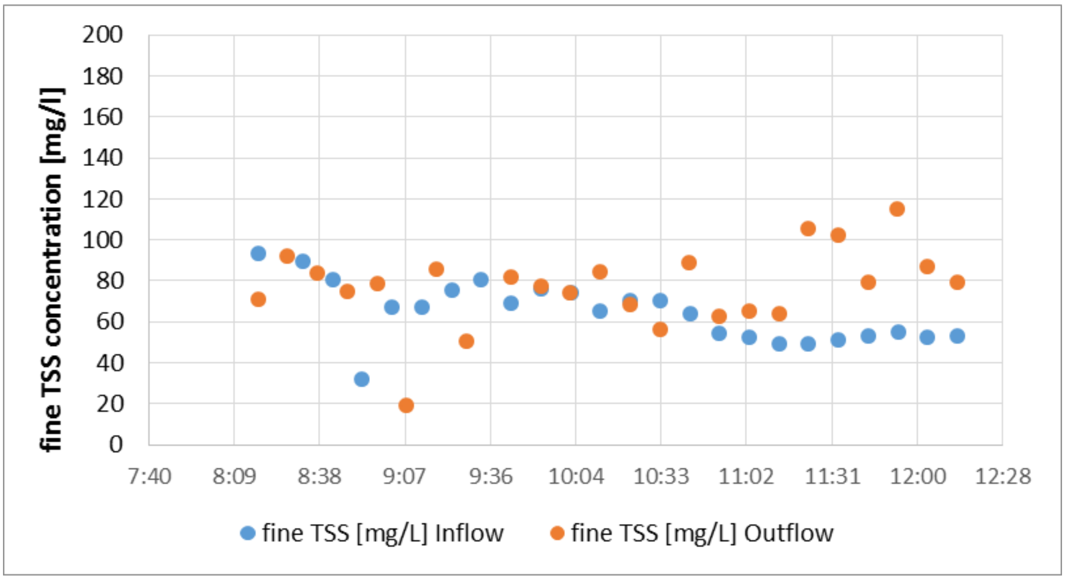


Figure 35 Fine TSS concentration during an exemplary dry weather test with a flow of 10 l/s.

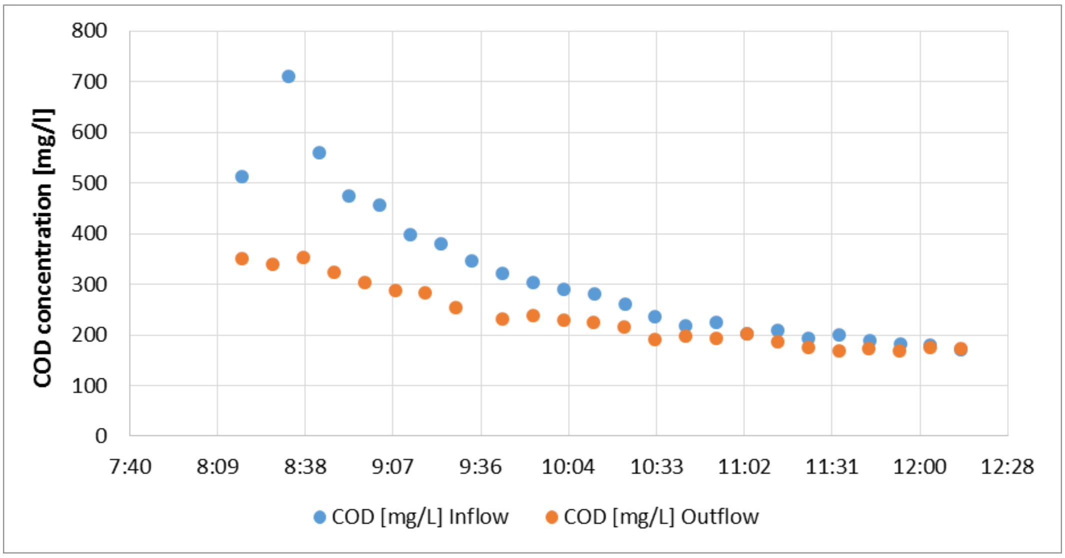


Figure 36 COD concentration during an exemplary dry weather test with a flow of 10 l/s.

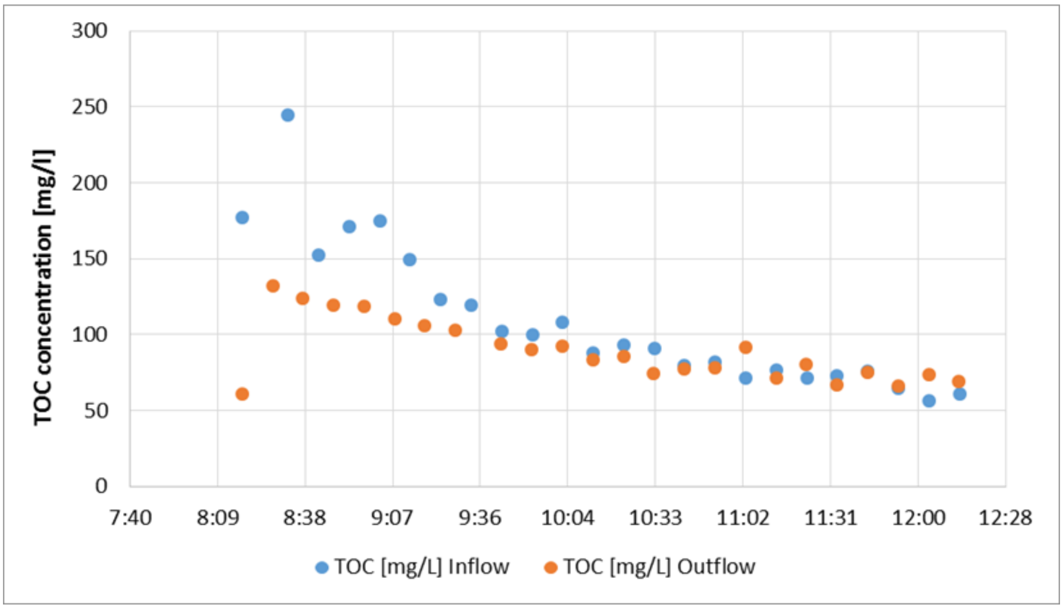


Figure 37 TOC concentration during an exemplary dry weather test with a flow of 10 l/s (corresponding to a surface loading in the container of 1.1 m/h).

The difference between the in- and overflow concentration at the beginning of a test decreases with increasing surface loading.

At the same time, it can also be observed, that the difference between in- and overflow concentration becomes smaller with decreasing inflow concentrations.

2.6.6. In- and overflow concentrations in relation to flow rate

Figure 37 to Figure 40 show in- and overflow concentrations for COD for flow rates of 10, 15, 20, and 25 l/s. These inflow rates correspond to surface loadings in the container of 1.1, 1.6, 2.2, and 2.7 m/h (Table 3). It can be seen that the difference between the in- and overflow concentration curves, which could be observed in the beginning of the test runs in Figure 34, Figure 36 and Figure 37 diminishes at higher flow rates (Figure 39 and Figure 40).

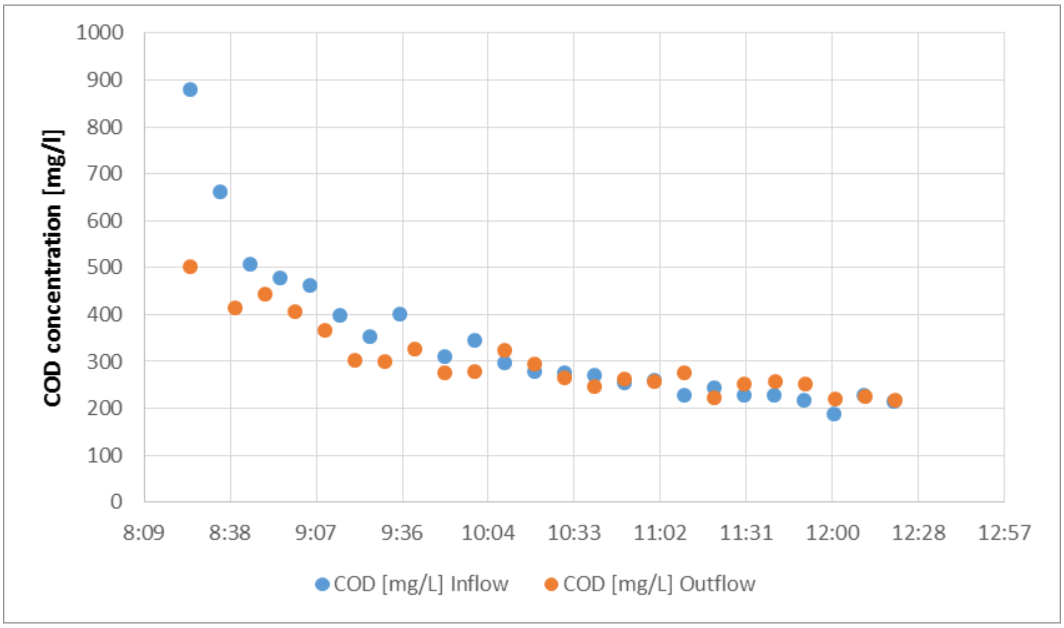


Figure 38 COD concentration during an exemplary dry weather test with a flow of 15 l/s (corresponding to a surface loading in the container of 1.6 m/h).

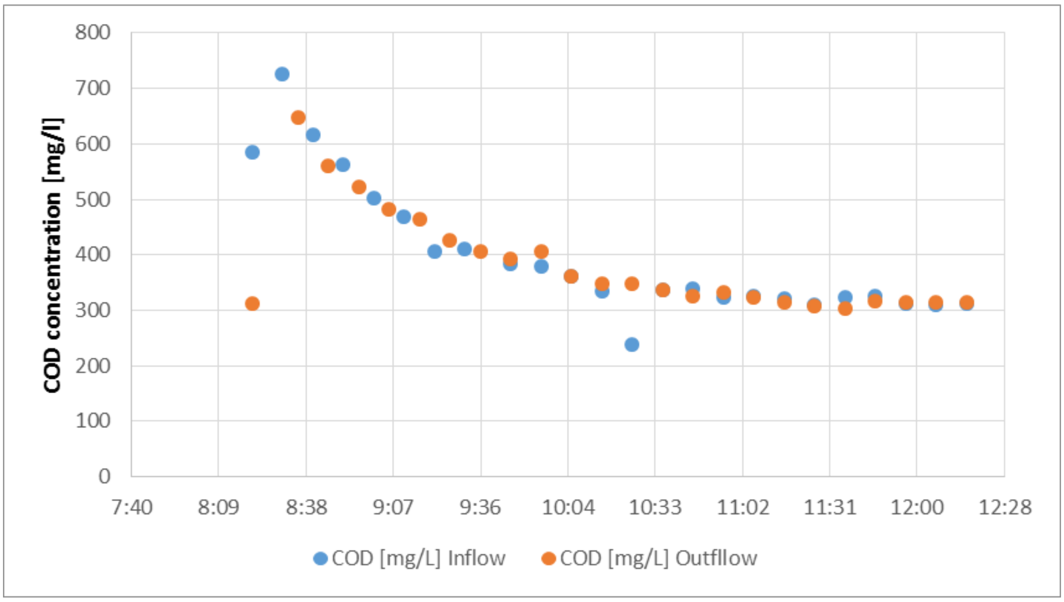


Figure 39 COD concentration during an exemplary dry weather test with a flow of 20 l/s (corresponding to a surface loading in the container of 2.2 m/h).

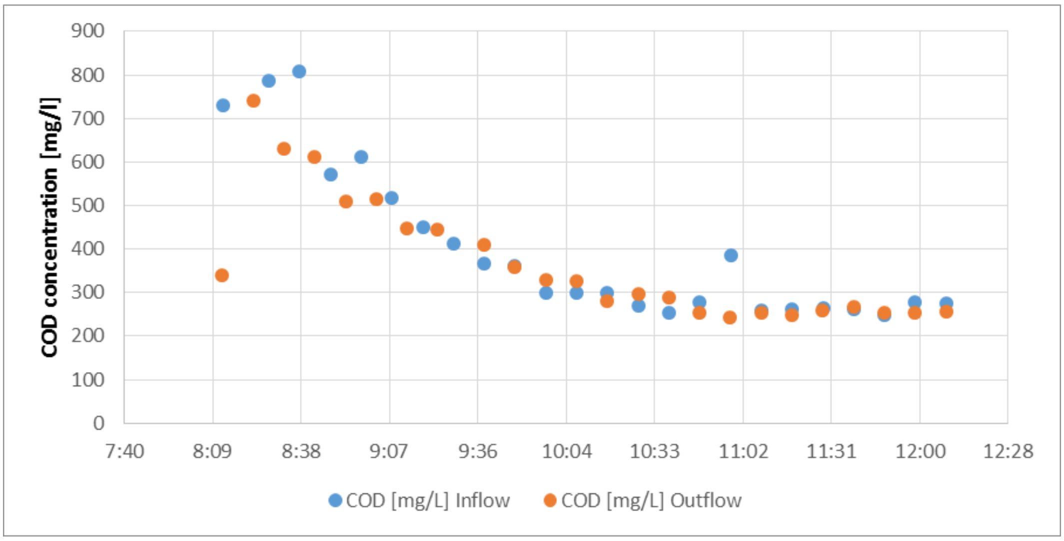


Figure 40 COD concentration during an exemplary dry weather test with a flow of 25 l/s (corresponding to a surface loading in the container of 2.7 m/h).

2.6.7. Sedimentation efficiency

From the difference in inflow and overflow concentrations, the sedimentation efficiencies were determined. For this, the mean concentrations of all inflow and all overflow samples of each event were assessed. In general, the reductions determined in this way show high variation, ranging from -46.6 up to 51.8 %. Negative reductions may represent no sedimentation or even a remobilization of sediment which was in the container already during the filling process, *i.e.* before the measurements started.

The boxplots below illustrate the reductions determined for different parameters and different flow rates (Figure 41 to Figure 44). Here, only positive reductions are reported. For all four parameters measured, the tendency of decreasing efficiencies with increasing flow rates is clear.

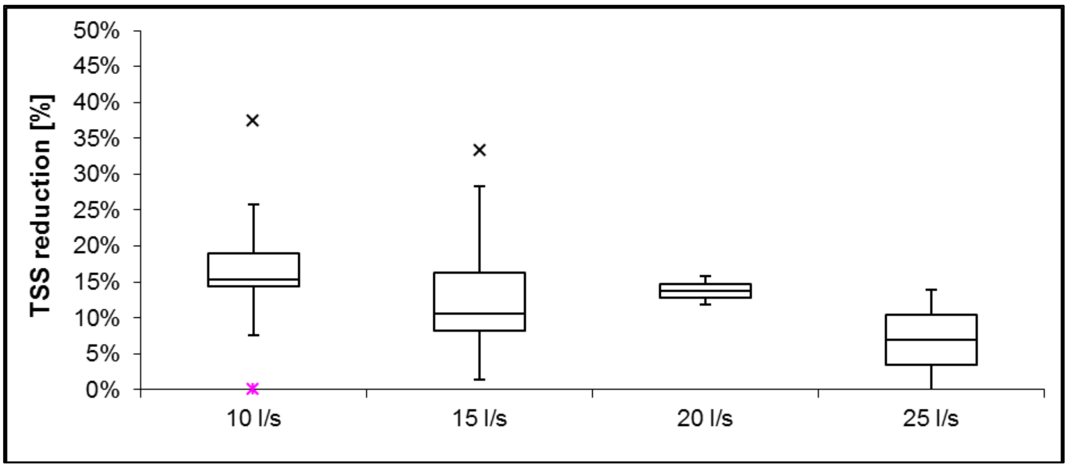


Figure 41 Reduction range for parameter TSS at different flow rates.

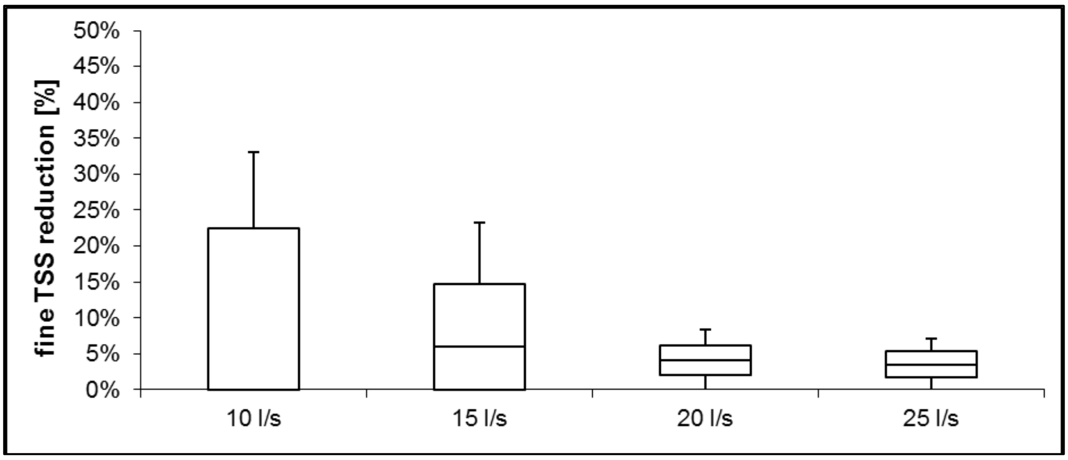


Figure 42 Reduction range for parameter fine TSS at different flow rates.

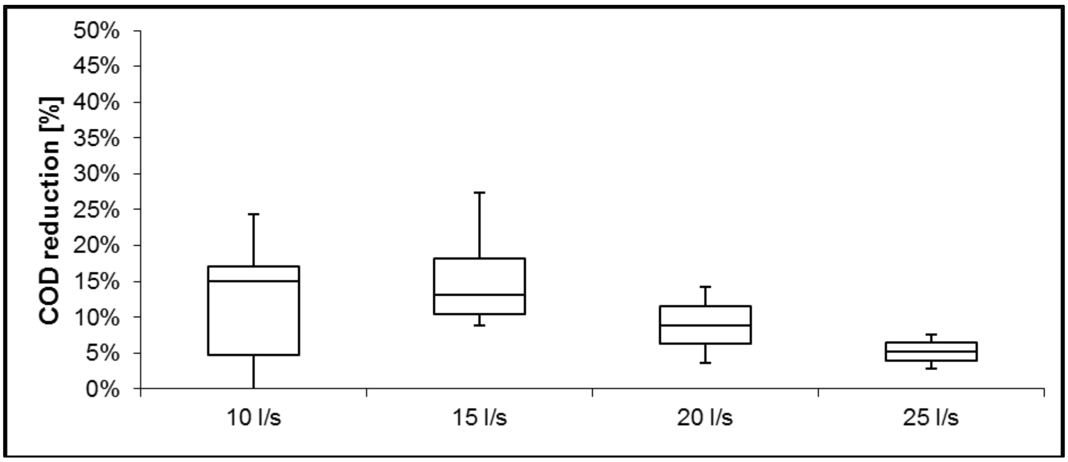


Figure 43 Reduction range for parameter COD at different flow rates.

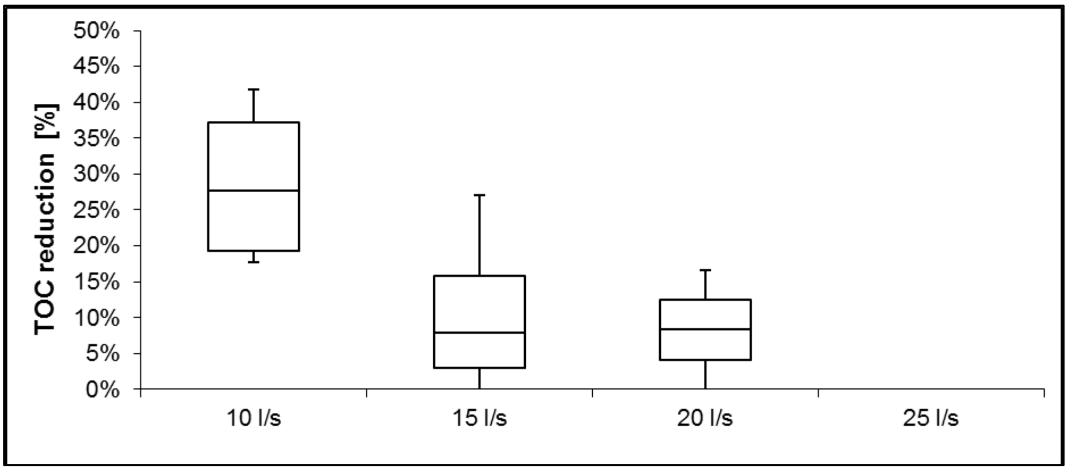


Figure 44 Reduction range for parameter TOC at different flow rates.

2.6.8. Inflow concentration determines efficiency

When analyzing sedimentation efficiency with respect to inflow concentrations, it was observed that the reduction in TSS, fine TSS, COD and TOC concentration was higher when inflow concentrations were high. To demonstrate this effect, Figure 45 to Figure 48 show the reduction in relation to the inflow concentration for four to five test runs. The hydraulic retention time determined by the Fluorescein tracer tests was applied to shift back the overflow concentrations by the corresponding time. The concentrations for every minute were calculated by linear interpolation between two measured concentrations.

This observation may be explained by the fact that in the sewer network, increasing flow corresponds to a higher sediment transport capacity of the flow, *i.e.* also coarser grains are transported. Thus, the sediment concentration in the flow is expected to be higher. A higher particle concentration can also improve flocculation. In the lamella settler, these coarser grains as well as flocculated particles are more efficiently settled.

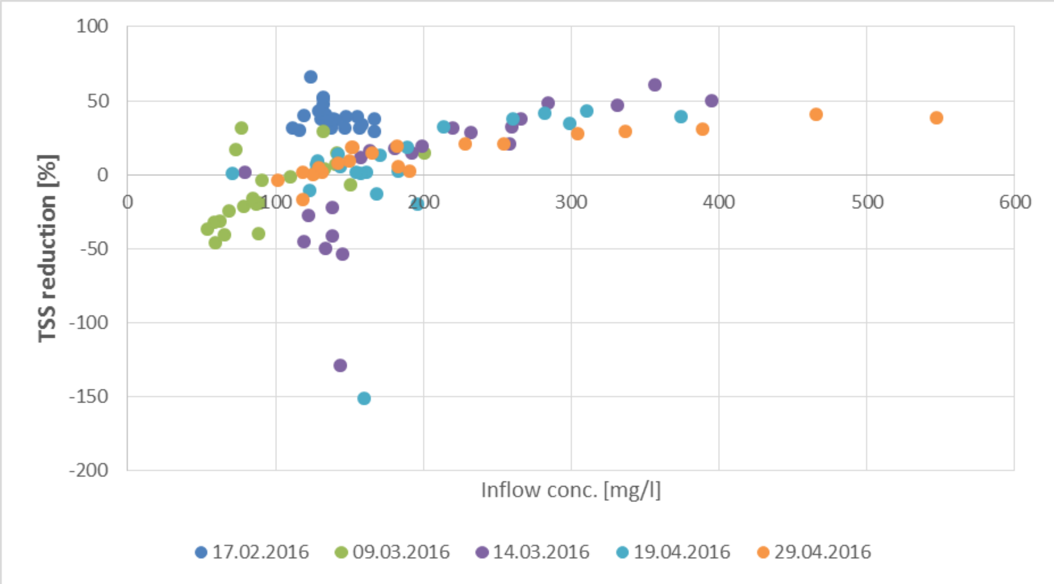


Figure 45 Concentration of TSS in the inflow and reduction on the way to the overflow for five test runs with dry weather at a flow rate of 10 l/s.

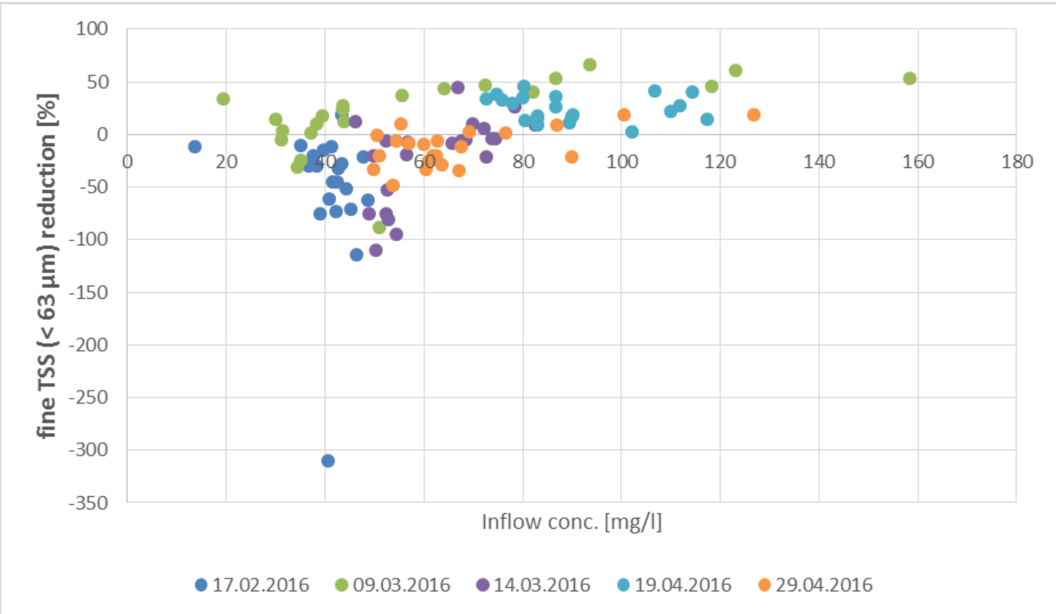


Figure 46 Concentration of fine TSS in the inflow and reduction on the way to the overflow for five test runs with dry weather at a flow rate of 10 l/s.

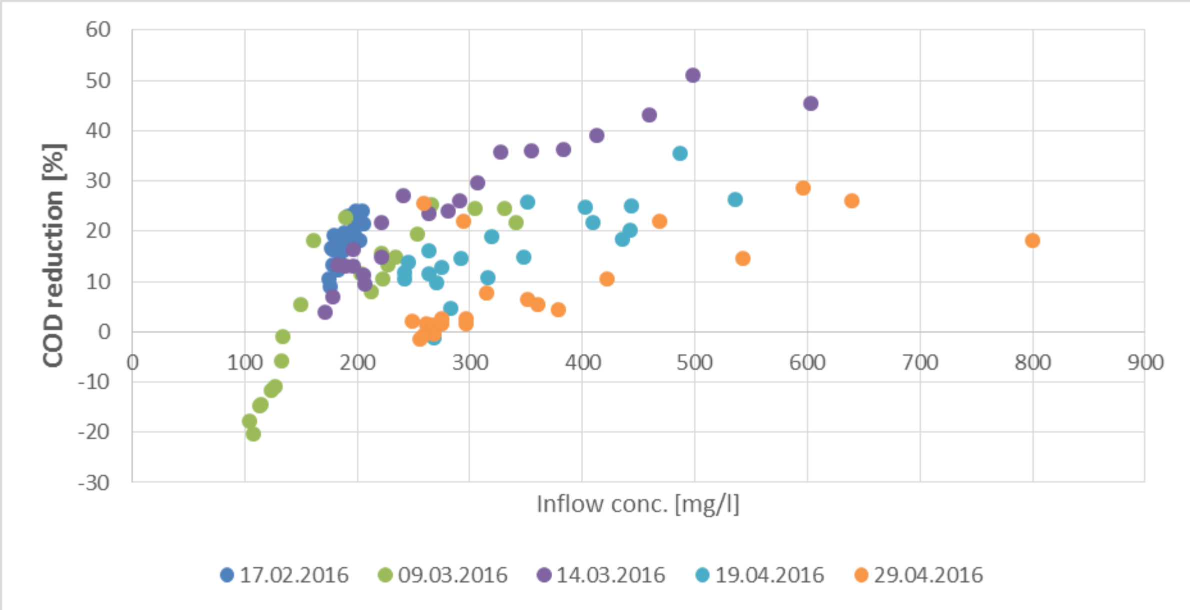


Figure 47 Concentration of COD in the inflow and reduction on the way to the overflow for five test runs with dry weather at a flow rate of 10 l/s.

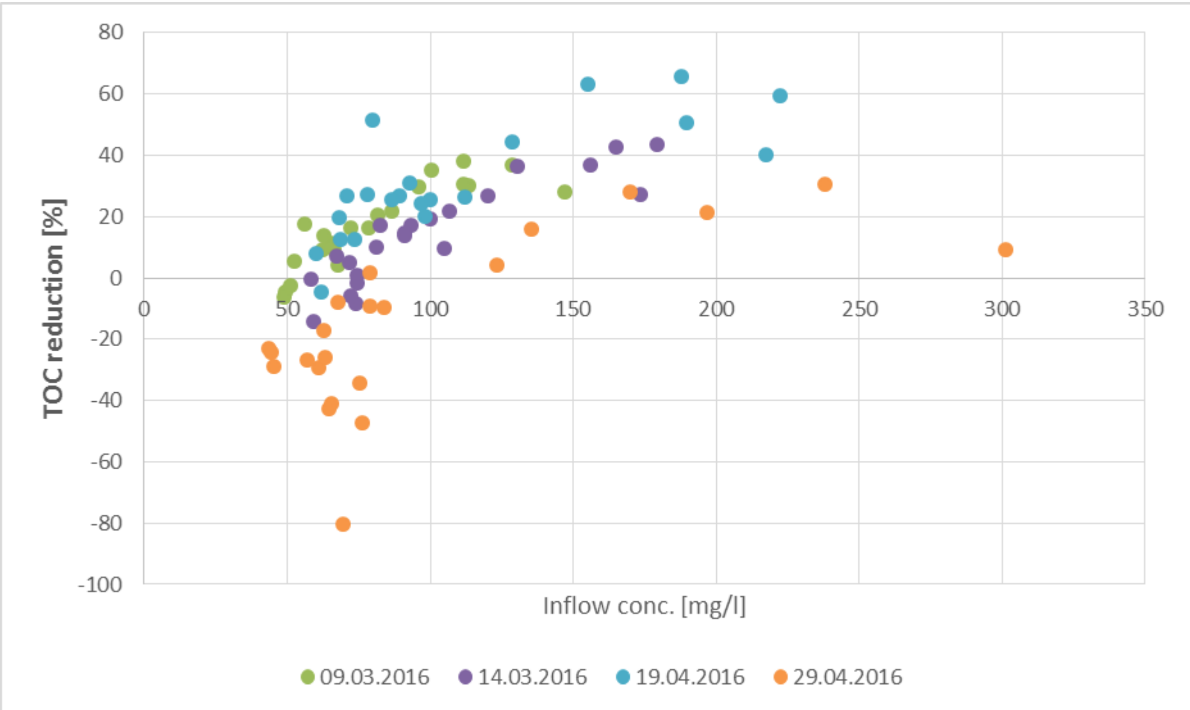


Figure 48 Concentration of TOC in the inflow and reduction on the way to the overflow for four test runs with dry weather at a flow rate of 10 l/s.

2.6.9. Sedimentation efficiency of container without lamellae

Tests runs without lamella packages were conducted at flow rates of 10, 15 and 20 l/s. Laboratory results show a high variance in the sedimentation efficiencies, varying between 0 to up to 40 % sedimentation efficiencies. Figure 49 and Figure 50 exemplarily show results for fine TSS and COD for one test run at a flow rate of 10 l/s.

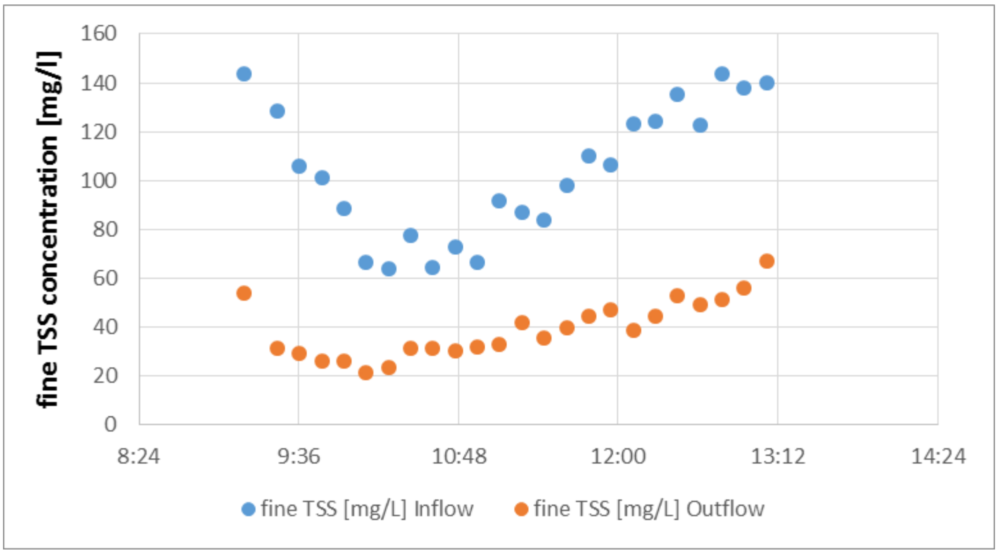


Figure 49 Fine TSS concentration during an exemplary dry weather test without lamellae with a flow of 10 l/s.

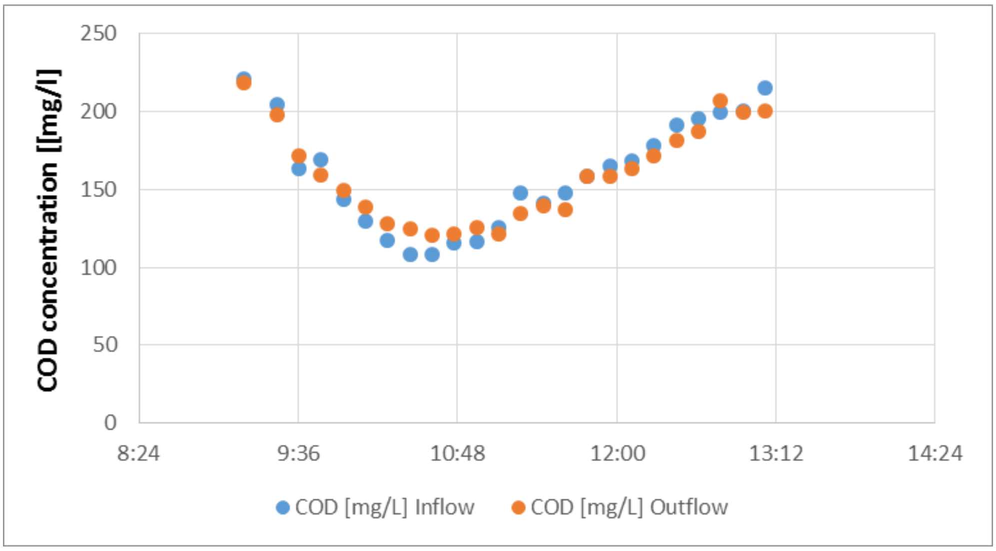


Figure 50 COD concentration during an exemplary dry weather test without lamellae with a flow of 10 l/s.

Due to the limited number of tests without lamellae, it is recommended not to use these results as a base for evaluating the share in the sedimentation efficiency of the container and the lamellae individually. As such a high variation has not been expected, only few tests without lamellae were scheduled before the container was shipped to Norway. It is advised to perform additional tests without lamellae.

2.7. Upscaling

2.7.1. Transfer to real CSO facility

For the transfer of the laboratory results to real life conditions, we decided to illustrate the sedimentation potential for an exemplary real CSO facility. Therefore, loads for one year (2014) at CSO Gartenstraße (upper Emscher) were modeled using the pollution load model MOMENT.

The sedimentation efficiency is highly dependent on the surface loading of a structure, which results from the surface area and the flow rate. The lamella surface in the container solution is 33.1 m^2. The container solution was tested with four different inflow rates and therefore four different surface loadings. Table 3 shows the altering inflow rates and corresponding surface loads.

Table 3 Inflow rates and corresponding surface loadings of the container.

Inflow rate [l/s]	Surface loading [m/h]
10	1.1
15	1.6
20	2.2
25	2.7

For the exemplary upscaling to CSO Gartenstraße, efficiencies demonstrated at 10 l/s (Figure 41 to Figure 44) were used for surface loads < 1 m/h and 15 l/s (Figure 41 to Figure 44) for surface loads > 1 m/h.

For the theoretically equipped CSO Gartenstraße it was assumed that 50% of the total storage volume (*i.e.* 50 % of 2211 m^3) was equipped with the same lamella type as in the container. The resulting surface loads calculated with the inflow data (year 2014) were mostly under 1 m/h (see Figure 51).

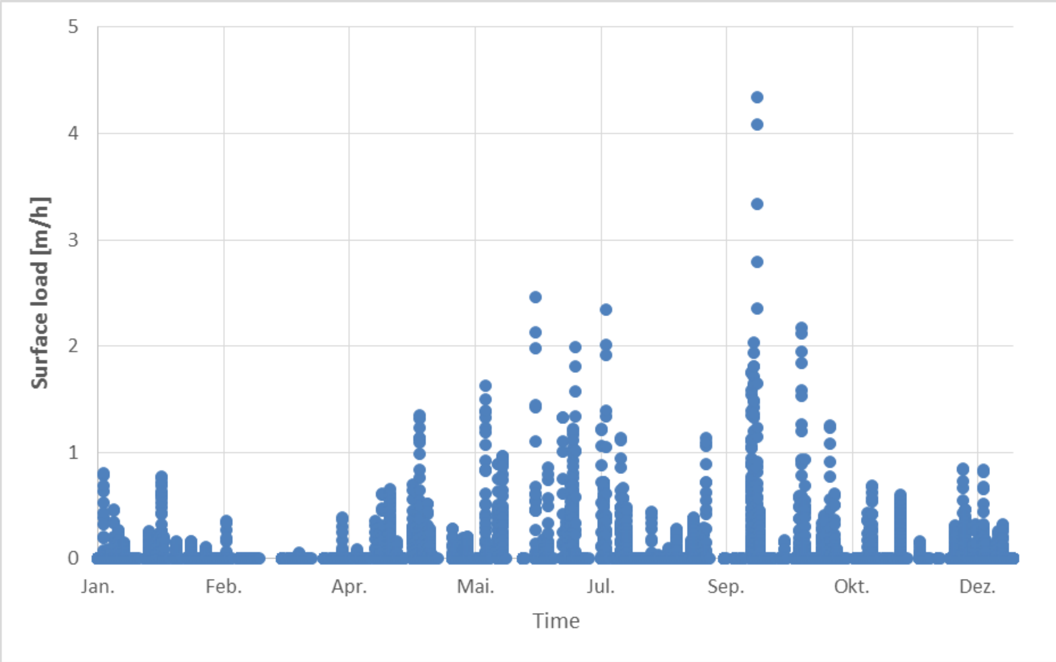


Figure 51 Theoretical surface loads (m/h) at CSO Gartenstraße according to inflow rates over one year (2014) with 50 % of the storage volume equipped with lamellae. One data point represents the surface load resulting from the given lamella surface and the inflow simulated in the MOMENT model every five minutes.

To determine the theoretical potential of the lamella settler, annually discharged COD loads from the overflow at CSO Gartenstraße were modelled. The efficiency rates determined in the test runs were then used to demonstrate the potential yearly load reduction in the overflowing water of this real CSO. For the calculation, three different efficiency rates were used, represented by the 25th, 50th and 75th percentile (Q1, Median and Q3) of the boxplots (Figure 41 to Figure 44). The reduction in overflow load compared to the overflow load at CSO Gartenstraße without lamella settler (“Original”) ranges from 5.9 (“Q1”) to 14.6 (“Median”) to 17.2 % (“Q3”) COD (Figure 52).

This is a rough estimation of the reduction of COD loads. It does not claim a high accuracy. The sedimentation efficiency depends on volume, surface, flow rate, and surface load. Here, we assume linearity and extrapolate the efficiency determined in the container tests to a real CSO facility equipped with lamella modules in a linear way.

Furthermore, we did not take the effect of the storage volume in reducing the discharged volume to the recipient river into account, as was done in D32.1. The container solution can store 33.1 m^2 of combined sewage which will not be discharged but will be transported to the WWTP after storage. Similarly, the exemplary full-scale CSO Gartenstraße can store 2211 m^3 of combined sewage which will not be discharged.

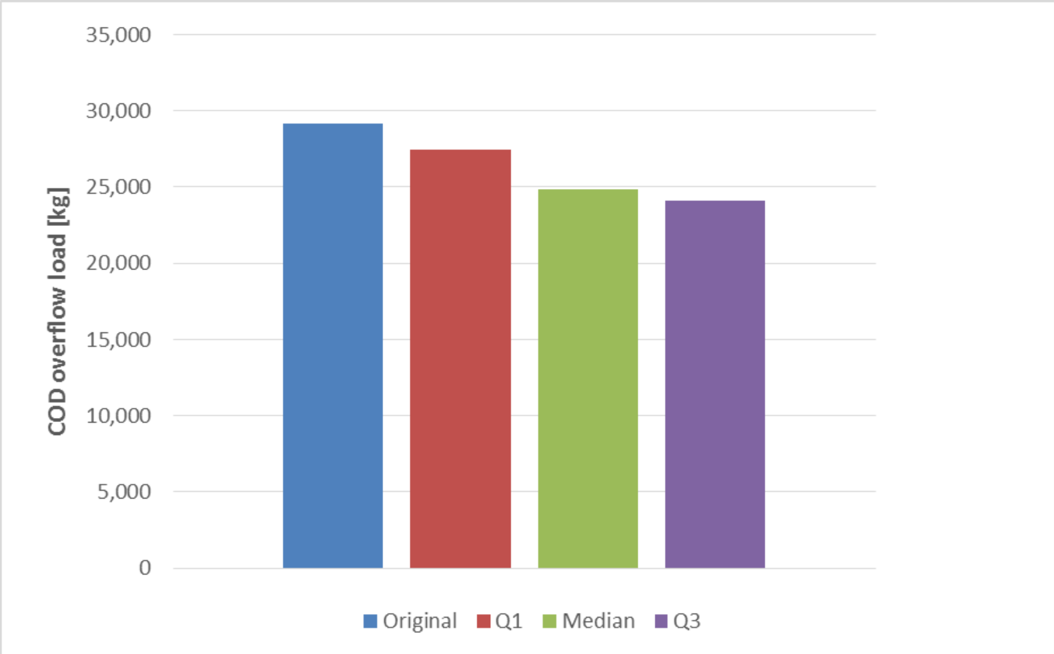


Figure 52 Theoretical COD load in the overflow of CSO Gartenstraße in one year (2014). "Original" refers to the overflow without lamellae, "Q1", "Median" and "Q3" represents the overflow with lamellae (storage volume equipped with lamellae by 50 %) modelled with the 25th, 50th and 75th percentile of the efficiencies determined in the container test, respectively.

For implementation in reality, several considerations need to be made. Concerning the technical feasibility, a refitting of existing CSOs is more easily possible in open facilities. Inserting the lamellae in closed basins requires a high effort. Furthermore, lamellae can rather improve sedimentation in rectangular storage basins than in round basins or circular storage channels.

According to these considerations, out of the 290 CSO storage facilities in the Emscher basin, 33 storage basins were identified, excluding all circular storage channels. Out of these 33 storage basins, four rectangular and open storage basins are reported in Table 4, as these are most suitable for refitting with lamellae.

Table 4 Rectangular and open CSO storage basins in the Emscher basin, excluding closed or round storage basins and circular storage channels.

CSO facility	Volume	Receiving stream	closed/open	rectangular/round
Gelsenkirchen Schalke-Nord-Springbach RÜB GE-Emscherstraße (Springbach)	4800	Emscher	open	rectangular
Bochum-Bleckstraße	790	Dorneburger Mühlenbach	open	rectangular
Gelsenkirchen-Sutum RÜB GE-Sutum	1348	Emscher	open	rectangular
Oberhausen Osterfelder Straße auf der „Emscherinsel"	1086	Emscher	open	rectangular

2.8. Conclusions

2.8.1. Efficiency

- The lamella settler in the container solution has the highest efficiency at a flow rate of 10 l/s and lower. The recommended surface load is thus about 1 m/h. This flow rate is considerably lower than the typical design criteria for lamella settlers in CSOs which is 4 m/h (personal communication, Weiss 2016).
- The container starts to be efficient at an inflow concentration threshold of approximately 300 mg/L COD.
- The efficiency ranges from 5 (1^{st} Quartile) to 17 % (3^{rd} Quartile) for COD.
- The maximal potential efficiency that can be reached with the lamella settler in its current setup is 37 % (TOC), 17 % (COD), 22 % (TSS fine) and 19 % (TSS).
- The particle concentration and type is of high importance for the efficiency.

2.8.2. Practical experience with test operation

At times, the pump in the pump sump was blocked and had to be cleaned. The self-cleaning mechanism of the lamellae, however, worked well and was sufficient. The pivoting device worked well and flushing two times with fresh water was sufficient to clean the container bottom.

2.8.3. Recommendations

- For testing in Norway and further sites, incoming water needs to have sufficiently high particle concentrations.
- A container operation independent of rain events is recommended.
- Measurement devices should be kept on the right side of the container.
- The container setup should be optimized to avoid water bypassing the lamella modules on the left side.
- Further measurements with and without lamellae should be conducted.

Figure 53 Transport of the container from Castrop-Rauxel to Hoffselva in Norway.

2.8.4. Outlook

The outcome presented in this report demonstrates that further testing of the lamella settler in the container setup is required. Particularly, testing with different combined sewage, *i.e.* different concentration and different sediment type, is recommended. A suitable site for such a second testing phase might be the pumping station at Dorneburger Mühlenbach at Blechstraße in Bochum or the CSO facility at the WWTP of the Körne stream in the Lippe catchment.

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4. Task 31.2 – Real Time Control of sewer network

4.1. Task description

Task 31.2 – Real Time Control of sewer network (M1-M42 EG, SEGNO, UDE)

Prior to a full scale implementation the interface requirements must be analyzed and the function blocks implemented in the RTC system.

- Conception of RTC system for implementation in the sewer system (SEGNO, EG).
- RTC system implementation (SEGNO, EG).
- Analysis of CSO load reduction potential (using hydrological model) (EG, UDE).
- Implementation of ADESBA RTC system (treatment of ADESBA Planner for the network, variant computation, PLC programs).
- Analysis of the congestion frequency in sewers (using hydrodynamic model) (EG, UDE).

4.2. Aim of the solution

Real Time Control (RTC) systems of sewer networks allow monitoring and actively controlling the water distribution in combined sewer canals. Different types of RTC systems currently exist – among them the rule-based and the model-based RTC (Schütze *et al.* 2004). The rule-based RTC relies on if-else-rules (Einfalt *et al.* 2001), decision trees, fuzzy-rule systems (Fuchs *et al.* 1994) or multi-value RTC concepts (Papageorgiou *et al.* 1987, Weyand 1992). Model-based RTC systems, however, use sewer models to predict system behavior in combination with algorithms and mathematical optimization. The effort to implement such RTC systems is very high.

In the ADESBA RTC solution, on the other hand, the controlling goal and concept is less complex, and thus, implementable with less effort. In ADESBA, the overall goal is to reduce the overflow volume into receiving waters in order to minimize negative effects of CSO on rivers. The same could be achieved by constructing larger combined sewer channels and storage basins, which would, however, come with the price of higher costs of investments and operation. With a RTC, however, this might not be necessary. Thus, a RTC can help to minimize costs of investments and operation.

An additional advantage of RTC as an alternative to larger infrastructure is the flexibility to adapt to changes of water use and emergence of wastewater in the future, resulting from demographic changes or to changes in the amount of rainwater per rain event, predicted to increase due to climate change. Furthermore, augmenting urbanization goes along with larger areas of sealed surface resulting and increasing amounts of rainwater discharged into the sewers instead of infiltrating into the groundwater.

4.2.1. ADESBA RTC algorithm

The basic principle of the ADESBA RTC algorithm is an equal fill level in all combined sewer storage facilities in the controlled network (Figure 54). This avoids that some CSO facilities experience overflows already, while others still have storage volume available. Thus, the entire storage volume of the system will be used. The overall goal is to reduce the overflow frequency and volume. Ideally, an overflow would only occur if all basins are filled but with this total storage volume an overflow cannot be avoided anymore.

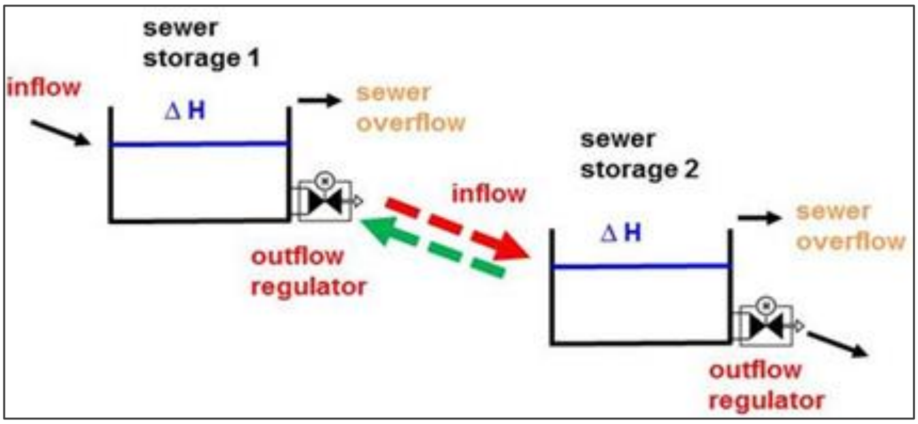


Figure 54 Overview of the real-time controlling mechanism of the ADESBA algorithm. ΔH = water level.

In the first step of the RTC process, ADESBA determines the inflow [Q_{zu}/Q_{in}] to each basin (Figure 55) in – ideally – minute by minute time steps. To this end, the measured outflow at the throttle [Q_d/$Q_{Drossel}$], the filling level [H_{ist}/H] and the change in the filling level [ΔH] are obtained. The overflow [Q_{ofl}/CSO] is calculated based on a measurement of the overflow water level and according to the Poleni formula.

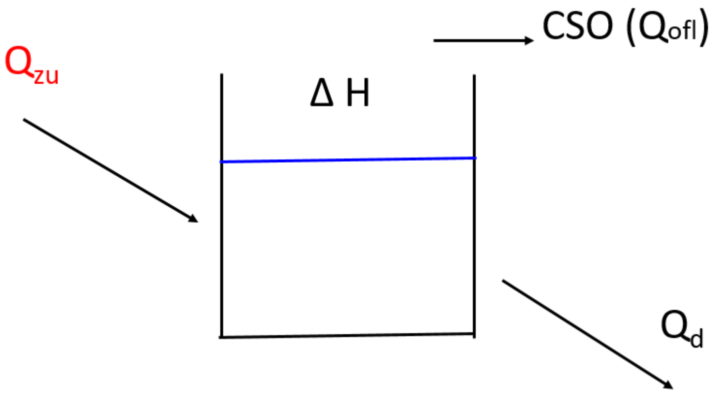


Figure 55 Parameters relevant for the calculation of the inflow (Qzu). The other three parameters (ΔH, Qd, CSO (Qofl)) are measured via sensors. ΔH = water level, Qzu = Inflow, Qd = throttled outflow, CSO (Qofl) = overflow.

Next, ADESBA checks for this time step, if the inflow can be discharged with the given throttle setting. During the beginning of rain events, the inflow usually exceeds the possible outflow with the current throttle settings. The upper basin, thus, sends a “wish” for opening of the throttle to the next lower basin (Figure 56).

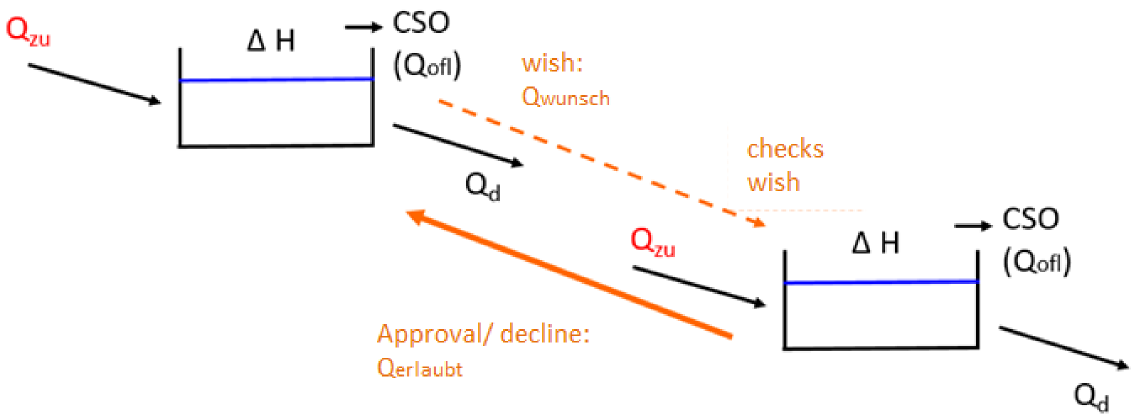


Figure 56 The upper basin sends a wish for a throttle setting to the lower basin, which checks the wish in relation to its own water level. ΔH = water level, Qzu = Inflow, Qd = throttled outflow, CSO (Qofl) = overflow, Qwunsch = desired throttle setting, Qerlaubt = approved throttle setting.

Then, ADESBA checks the state in the lower basin and evaluates if the wish of the higher basin can be approved. This wish is then approved, declined or an approval for a less strong throttle opening is given and a response is given to the upper basin. Additionally, the upper basin formulates a water level target in order to reach equal filling.

In the following table (Table 5), all relevant parameters of state in ADESBA are listed.

Table 5 Relevant parameters in ADESBA describing the state of the basins and the RTC.

State describing parameters of basins/RTC		Parameter name
Hist	Water level [m] or [%]	$.PLC.Hist $.RTC.Hist
Qzu	Inflow [m³/h]	$.PLC.Qzu
Qd	Current throttle outflow [m³/h]	$.PLC.Qd
Q	Targeted throttle outflow [m³/h]	$.RTC.Q
Qofl	Current overflow [m³/h]	$.PLC.Qofl
LCIn	Life signal response value	$.PLC.LCIn $.RTC.LCIn
LCOut	Life signal questioning	$.RTC.LCOut $.PLC.LCOut
M_state	Status: 0 = dry weather, 1 = rain weather	$.RTC.M_state
M_qstor	Max. water volume [m³] that can be emptied per day, no inflow	$.RTC.M_qstor
M_qfreethis	Water level [m³] that is emptied per day, with current water level	$.RTC.M_qfreethis
R_bset	Target water level [%] of the lower basin to be adjusted towards	$.RTC.R_bset
R_Wunsch	Target outflow [m³/h]sent to the lower basin for approval	$.RTC.R_Wunsch
R_Erlaubt	Approved outflow [m³/h] sent to the upper basin, based on the own filling level	$.RTC.R_Erlaubt

As sewer networks usually have several basins connected in row and in parallel, ADESBA needs to coordinate these single sections. This coordination is achieved by communication of the outflow and own filling level (in %) of the lower basin as a filling level target to all higher basins. In the next time step, ADESBA determines outflow wishes in accordance to the filling level target. Important is the change in the filling level from one time step to the next. At the throttle, the change in the inflow ΔQ_{in} is recognized and the outflow wish is formulated accordingly.

4.2.2. Efficiency reported in literature

In the Emscher catchment, two RTC-strategies have been developed and tested in the past (Pfister & Teichgräber 1995, Pfister *et al.* 1998, Petruck *et al.* 2003). These were RTC systems controlling the combined sewer system using radar-measured precipitation for forecasts. They applied the “fuzzy logic” using “if-then-cases”. In 1994, EG and itwh (Institut für Wasserwirtschaft der Universität Hannover) simulated and implemented a volume based RTC in the catchment of the WWTP Gelsenkirchen-Picksmühlenbach (Pfister & Teichgräber 1995). In a follow-up, pollution levels were considered as well (Petruck *et al.* 2003). However, the implementation and operation effort was extremely high and the volume of CSO could be reduced by 5% per year only (Petruck *et al.* 2003). In 2010, the controlling potential of the catchment of the WWTP Bottrop and Emschermündung was assessed (Mang *et al.* 2010). Furthermore, the potential analysis was extended by considering also RTC of the WWTPs and the main sewer running alongside the Emscher as well as the sewers along the Emscher tributaries.

4.3. Description of demo case

The Emscher catchment holds about 300 CSO facilities (Grün *et al.* 2015). Most of the storage facilities are inline storage sewers (SKUs, *i.e.* “Stauraumkanal mit untenliegender Entlastung”). Part of the storage facilities, however, are storage basins connected in parallel to the sewers. This leads to a total storage and decentral treatment (by sedimentation) capacity of 638,000 m^3. As the sewer system needs to be flexible to adapt to future changes, testing a RTC system is of high interest in the Emscher catchment.

Interface requirements and conception of the ADESBA-RTC system

The ADESBA algorithm was developed by ifak (Institut für Automation und Kommunikation e. V., Magdeburg, Germany, Alex *et al.* 2008) and implemented in the simulation software Simba#, a program also developed by ifak. Simba# uses a graphic user interface and is mostly used for modelling processes regarding wastewater treatment or biogas production. The software is also able to model sewer systems with respect to volume and quality. The ADESBA modules in Simba# simulate the changes of combined sewer overflows in existing sewer networks with the addition of the ADESBA-RTC.

SEGNO has brought these theoretical Simba# modules into practice by embedding the ADESBA algorithm into a PC and coupling it with an interface (the ADESBA Planer) For simulation and configuration of the existing sewer system, SEGNO developed the tools ADESBA Planer and ADESBA CALC. Detailed information on the conception of the RTC can be obtained from DESSIN Milestone MS7.

4.4. Implementation process

4.4.1. Planning

Requirements for a suitable test area

Requirements for the RTC are: up-to-date PLC systems (Siemens S7-300), automatically controllable continuously variable throttle valves in the outflow pipes, magnetic flow meters in the outflow pipes, up-to-date hard- and software for visualization and archiving (Win-CC and ACRON, respectively), data transfer via online (DSL) or quasi-online (UMTS) connection, ideally fallback options, measurement sensors for water levels in the storage basin/channel and at the overflow bar.

Selection of a suitable test area

Five CSO facilities were selected as promising. These were five stormwater treatment tanks connected in series, located in the Emscher sub-catchment of Dortmund Deusen (Figure 57).

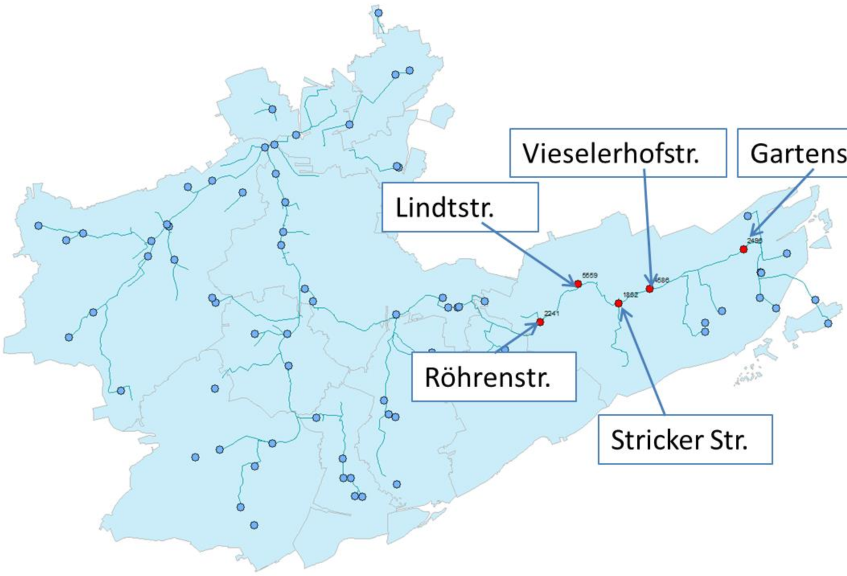


Figure 57 Network of the five CSO facilities in the Emscher sub-catchment of Dortmund Deusen to be real-time controlled.

In order to check the suitability of these facilities, the following information was gathered on each of them:

- Storage basin characteristics (volume of storage basin plus volume of the incoming sewer, ground level and overflow level of the CSO).
- Currently set minimal, maximal and nominal throttle flows (Qmin, Qmax, Qnominal).
- Presence of sensors (flow meters at the inflow and outflow, water level sensors in the storage basin and at the overflow bar).
- Type and model of the local control (PLC).
- Necessity of operational improvement according to current overflow frequencies.
- Presence of communication equipment for data transfer.
- Cost estimation for re-fitting of hardware, software and communication equipment.
- Water run time to next CSO.
- Throttle run time.
- Water-level-to-storage-volume relation.

Part of this information is presented in Table 6.

Table 6 Properties/settings of the five tested basins.

	Röhrenstr.	Lindstr.	Strickerstr.	Vieselerhofstr.	Gartenstr.
Volume [m³]	2336	6214	2590	3349	3371
Hmax [m]	4.65	4.6	4.6	3.6	4.2
Qnom [m³/h]	2808	2556	2052	1674	1080
Qmin [m³/h]	1404	1278	1026	837	540
Qmax [m³/h]	2808	3834	3078	2511	1620
Flow time [min]	0	13	11	13	44

Further parameters relevant for ADESBA are listed in Table 7.

Table 7 Relevant parameters for the basins and the RTC in ADESBA.

Parameter basin/RTC		Parameter name
α (alpha)	Relative control enhancement	$.RTC.P_a
β (beta)	Rain water threshold: Relative water level, between 0 and 1	$.RTC.P_b
tstor	Emptying time, no inflow	$.RTC.P_tStor
Cqin	Factor for determining the outflow wish: Outflow = C_{qin} * Inflow	$.RTC.P_Cqin
eps	Maximum of the filling level: Safety threshold (100%-eps), above which the basin is regarded as full	$.RTC.P_eps
eps2	Minimum of filling level: Safety threshold, below which the basin is regarded as empty	$.RTC.P_eps2
kdamp	Buffering factor for the predictive model, between 0 (pessimistic) and 10 (optimistic)	$.RTC.P_kdamp
Min.-Band	Effective min. throttle setting, influences Qmin (Qmin = 100%)	$.RTC.P_bMin
Max.-Band	Effective max. throttle setting, influences Qmax (Qmax = 100%)	$.RTC.P_bMax
Qmin	Threshold min. outflow [m³/h]	$.RTC.Qmin
Qmax	Threshold max. outflow [m³/h]	$.RTC.Qmax
Qnom	Nominal outflow [m³/h]	$.RTC.Qnom
LCTimeout	Connection timeout [s]: time to wait until a connection error is reported	$.RTC.LCTimeout
Name	Name of a basin	$.RTC.Name
Kommentar	Comment to a basin	$.RTC.Comment
Volumen	Storage volume of a basin [m³]	$.RTC.V
Laufzeit	Water flow time to the next basin [min]	$.RTC.TF

Table 8 reports the selected settings for these parameters for the five basins in the demonstration study.

Table 8 Equal settings of the ADESBA RTC parameters for the five basins.

Parameter	Setting	Description
β (Beta)	50%	Rain weather threshold
eps	5%	Max. filling level
eps2	1%	Min. filling level
Qnom	2QT	Nominal throttle setting
Qmin	1QT = 0.,5*Qnom	Min. throttle setting
Qmax	3QT = 1.5*Qnom	Max. throttle setting
Min.-Band	100%	Effective min. outflow
Max.-Band	100%	Absolute max. outflow

Preparation: Seminar at ifak (ADESBA RTC algorithm developer)

Two workshops on Simba# and ADESBA were held at ifak in Magdeburg. The questions that were focused on were:

- How does the Simba# model and the ADESBA algorithm work?
- What needs to be considered - and potentially adapted - when controlling circular CSO storage channels instead of rectangular CSO basins?
- Which influence do potential errors due to uncertainties in the water-level-to-storage-volume relation have?

The introduction of the Simba# software enabled UDE to set up the tested system in the model and run the simulations. The knowledge gained in the workshops fed into the implementation of the RTC and is documented in minutes of the meetings.

Preparation: Visit of existing ADESBA RTC site

ADESBA has been implemented in the city of Hildesheim (Germany) for testing purposes. The real-time controlled system in Hildesheim is described in Pabst *et al.* (2010).

EG's operating department, thus, visited the site in Hildesheim and talked to the site owner and operator to learn about the experiences gained in Hildesheim. A direct comparison of the two "demonstration cases" is not possible because the systems are very different, as in Hildesheim the control algorithm was implemented in each PLC separately and the communication was restricted to data transfer from one storage basin to the next. No global communication, and thus, no overview of the overall sewer system was in place.

4.4.2. Analysis of potential

a) Evaluation of historical operational data

In a first step, the controlling potential was estimated by evaluating existing operational data. Besides structural information about the facilities (Table 6), operational data on the water levels inside the five tanks were provided for a one year period (11/2010 – 10/2011). Water levels were translated into relative filling degrees with the use of the water-level-to-storage-volume relationship. Next, rain events at which at least one tank was overflowing were detected (filling degree > 100%) and counted.

Table 9 shows the result of the evaluation of the operational data. In total 41 CSO events were detected. The highest number of events with potential has the tank at Lindtstr. In 78% of the cases this tank still provides some potential storage. The tank at Röhrenstr. has empty storage volume in only 5% of the cases. In general, the tank at Röhrenstr. is most likely to have overflow. This tank showed a high frequency of overflows, and thus, has a low potential.

Table 9 Number of overflow events in operational data (11/2010 – 10/2011) and number of overflow events with available storage potential (11/2010 – 10/2011), *i.e.* partly empty storage volume.

	Total CSO events with minimum one tank overflowing	CSO events with storage potential	Gartenstr. with potential	Vieselerhofstr. with potential	Strickerstr. with potential	Lindtstr. with potential	Röhrenstr. with potential
Number of events	41	37	24	27	32	29	2
Percentage of total events		90%	59%	66%	78%	71%	5%

In addition, the same analysis with a similar procedure has been performed with data from the pollution load model MOMENT (Figure 58, Table 10). The dataset consisted of information on inflows, outflows and overflow of tanks modelled for a period of 20 years.

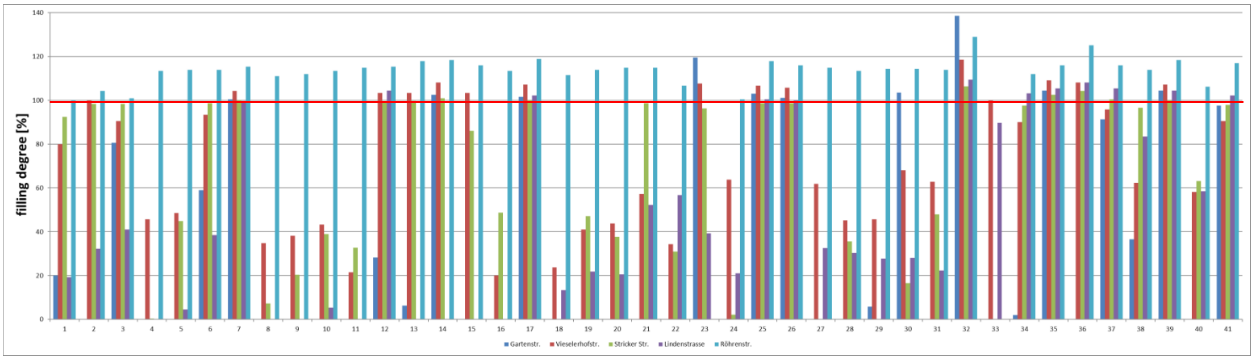


Figure 58 Filling degree (%) of each of the 5 CSOs at 41 rain events. The filling level 100 % is indicated by the red horizontal line. Columns indicate filling level of each of the 5 CSOs (blue - Gartenstr., red - Vieselerhofstr., green - Strickerstr., purple - Lindtstr., turquoise - Röhrenstr.).

Table 10 shows the numbers of CSO events in total, the number of events with storage potential per year in total and per tank as well as the mean values over 20 years.

Table 10 CSO events with storage potential using modelled data (MOMENT Model).

Year	total number of CSO events	number of CSO events with storage potential	Gartenstr.	Vieselerhofstr.	Strickerstr.	Lindtstr.	Röhrenstr.
1992	85	48	31	44	32	29	2
1993	99	42	21	38	26	33	0
1994	88	45	31	40	36	30	4
1995	46	38	24	34	28	27	5
1996	89	44	27	39	31	26	3
1997	76	25	11	21	15	11	3
1998	76	37	23	31	31	22	4
1999	97	48	35	44	36	24	6
2000	98	53	34	48	42	34	7
2001	87	40	29	37	34	33	0
2002	82	35	17	30	24	22	6
2003	78	38	18	34	26	23	9
2004	93	50	29	43	38	38	2
2005	81	41	22	34	23	27	4
2006	76	40	18	34	26	30	4
2007	105	53	35	46	44	31	8
2008	83	37	22	27	26	23	4
2009	78	39	27	33	26	25	2
2010	68	24	17	23	19	18	1
2011	69	38	26	31	24	23	2
Mean	**82.7**	**40.75**	**24.85**	**35.55**	**29.35**	**26.45**	**3.8**

The results generated with the MOMENT data are comparable to those generated with the operational data. The tank at Röhrenstr. is most likely not to have a high potential due to the high number of overflows compared to the other four tanks.

In addition to determining the number of CSO events with free capacities in each tank, the free storage volumes inside the tanks were quantified. Figure 59 shows the general procedure of the data evaluation. Considered are events where at least one out of five facilities recorded a spillage. For each of these events, the maximum water levels were converted into minimum free storage volume. This was done by using structural information of the tanks and the water-level-to-water-volume relation. Minimum free storage capacities of all considered events show the medium and distribution of free storage volumes for each tank (Figure 60).

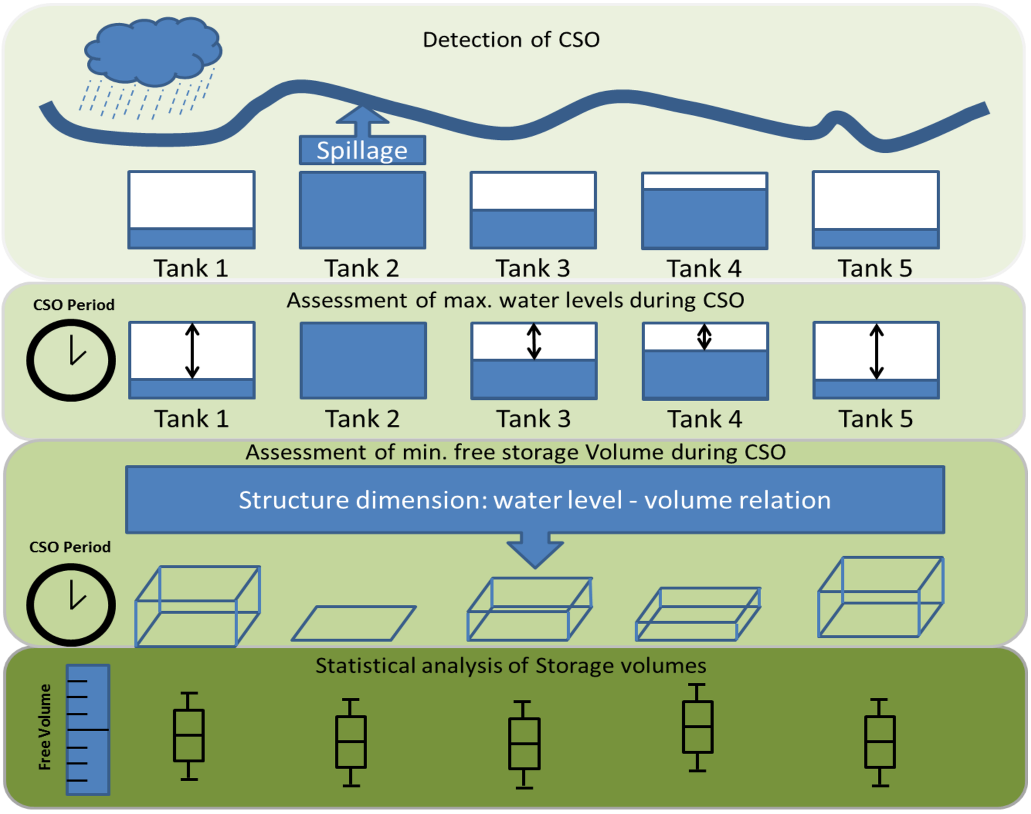


Figure 59 General procedure of the data evaluation using potential storage volumes.

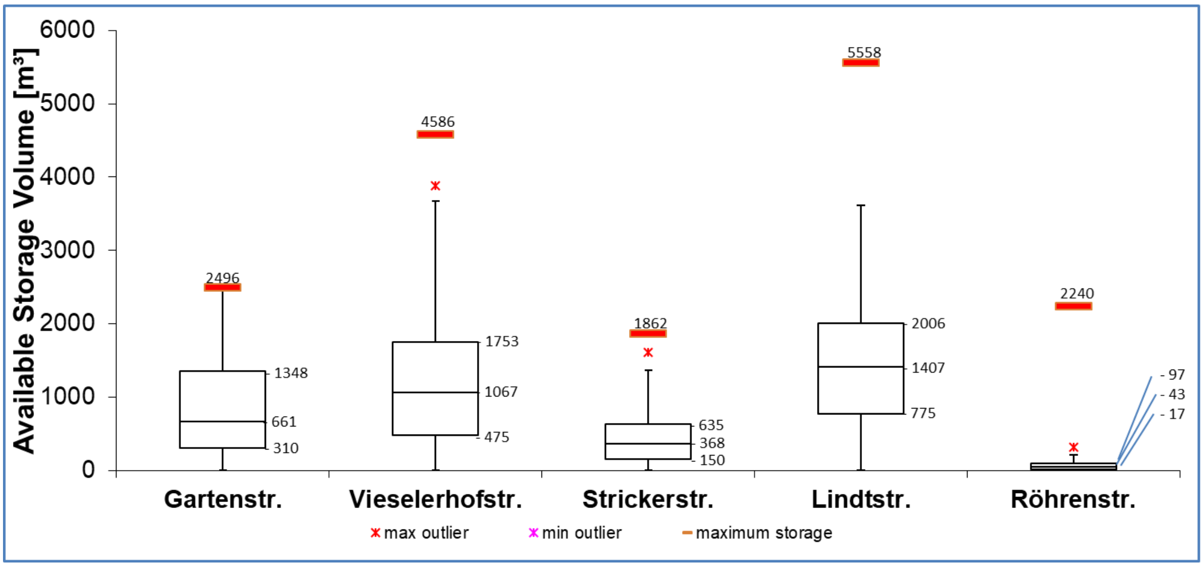


Figure 60 Minimum available storage volume (m^3) in each tank.

The analysis of available storage volumes shows that in average one quarter of the storage volume is available for additional water (Table 11). This quarter of the storage volume could be used more efficiently by a RTC of the system. The analysis of the volume also reveals the lowest potential at the tank at Röhrenstr. This means that this tank does not only have the fewest events with storage capacity but also the least volume available in those cases, where it is not fully filled.

Table 11 Percentage of the storage volume of each tank that is available for uptake of additional combined sewage.

	Gartenstr.	Vieselerhofstr.	Strickerstr.	Lindtstr.	Röhrenstr.
Relation median/ total storage volume	26.5%	23.3%	19.8%	25.3%	1.9%

b) Simulating the effectivity of the ADESBA control algorithm in SIMBA#

After this first assessment of potential, the entire sub-catchment of the upper Emscher - in which also the five CSOs are located - was considered to be worthy for further investigations and a possible extension of the ADESBA-RTC system.

Figure 61 shows the general structure of the ADESBA control system in Simba#. Local controllers at each tank gather information about flows and filling degrees at each tank. The supervisory controller collects the information from each tank and generates permissions for throttle flows to balance the filling degrees at each tank.

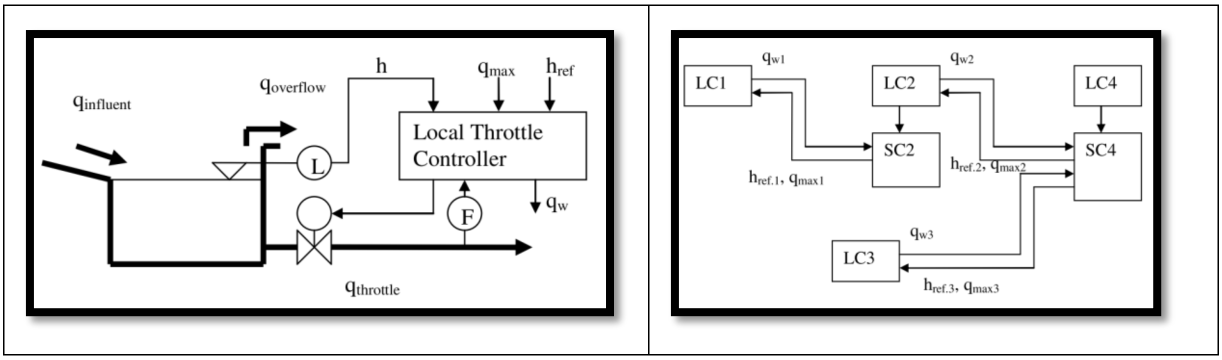


Figure 61 RTC structure of ADESBA using local (LC) and supervisory (SC) controllers (Alex *et al.* 2008).

The sub-catchment of the upper Emscher including the five tanks was modelled in Simba#. Figure 62 gives an impression of the system in Simba#. It shows the graphic user interface of the sub-catchment including the five tanks with lateral inflows and the ADESBA controllers.

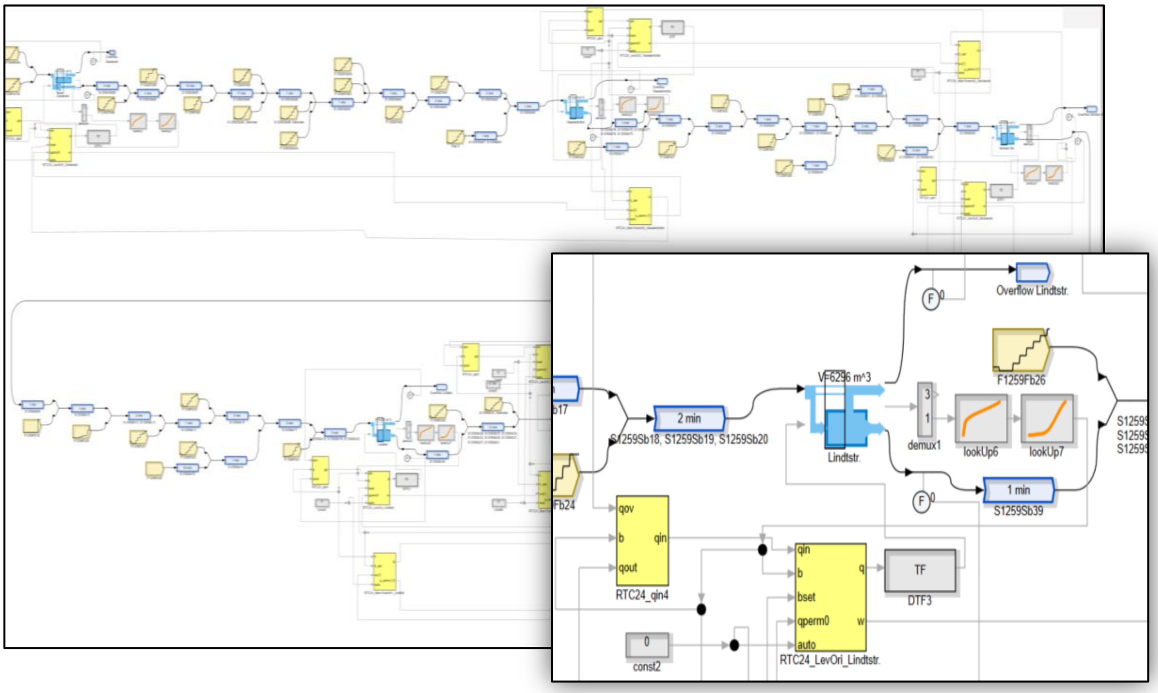


Figure 62 Structure of the network of the five CSO facilities to be controlled in Simba# including controllers.

Inflows from impervious areas were generated by using modelled data from the pollution load model MOMENT in use by EG. Therefore, exported data was formatted into files readable by Simba#. A script using Python programming language has been coded to perform the formatting for each file of discharge data modelled in MOMENT for 25 years (1990-2014).

Crucial information of the sewer system under investigation was the type of tank structure, the storage volume, throttle flows and flow times between tanks. The storage volume for each tank was assessed by EG. To be as precise as possible, storage volumes of the tank as well as of the connected sewers were calculated. These volumes, flow times and permitted throttle flows were used as the basis for the simulations in Simba#. In these simulations, CSO events with and without ADESBA in 25 years were compared in terms of overflow volume, overflow counts and overflow days to show the efficiency of the system.

Additional tests on the sensitivity of the system concerning the range of throttle operation, the effect of uncertainty in the water level-to-storage-volume relationship and the dependency on individual tanks were also done (see sub-chapter "Analysis of sensitivity").

Simulation in Simba# with and without ADESBA (25 years)

Overflow volume, counts, and days assessed in Simba# with and without ADESBA are presented in Figure 63 to Figure 65. With ADESBA, the theoretical total overflow volume of all tanks could be reduced by 8.7 %. The assessment shows that the main part of the saved overflow volume is due to the tank at Vieselerhofstr. The other tanks show higher or similar overflow volumes compared to without the RTC. Also for the overflow counts and days, the main effect was due to the tank at Vieselerhofstr. It is to be noted that the theoretical total overflow counts and days are higher with ADESBA than without. The target parameter, which is the overflow volume, however, could be reduced within the system.

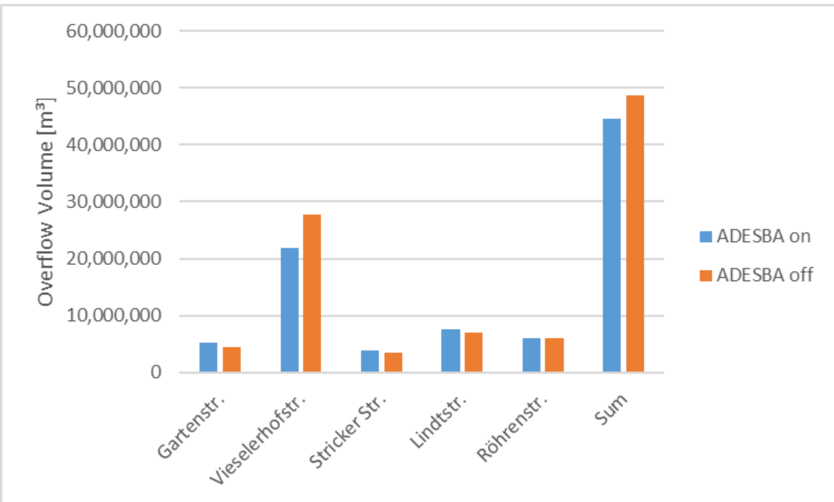


Figure 63 Overflow volume for each CSO facility and summed up overflow volume of all five facilities calculated in Simba# with and without ADESBA.

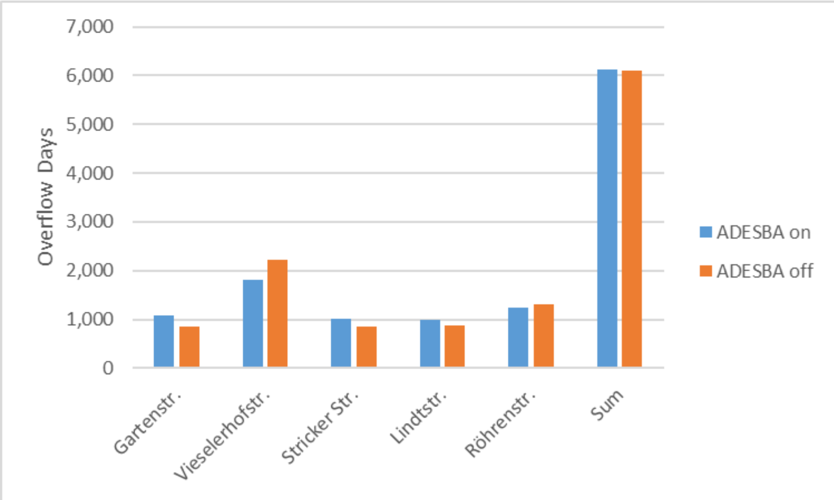


Figure 64 Overflow days for each CSO facility and summed up overflow volume of all five facilities calculated in Simba# with and without ADESBA.

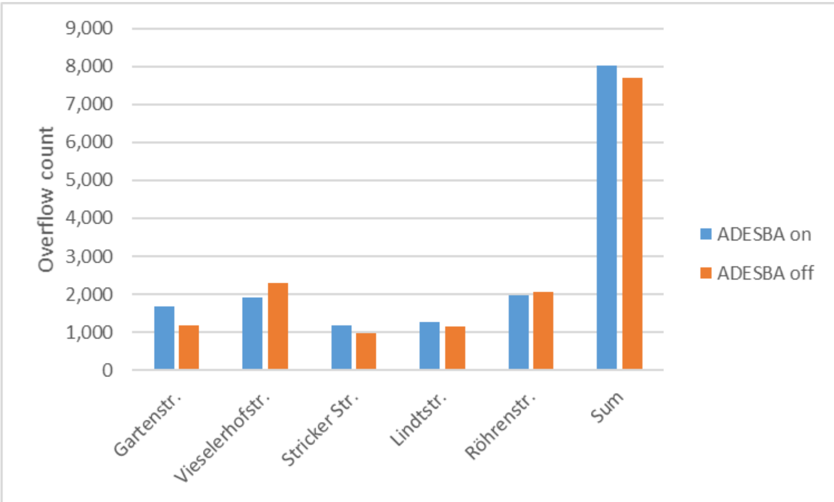


Figure 65 Overflow count for each CSO facility and summed up overflow volume of all five facilities calculated in Simba# with and without ADESBA.

Analysis of sensitivity

ADESBA operates by opening and closing the outflow throttles at the CSO tanks. These can be controlled in a given range. In general, the upper border is determined by the maximum flow the sewer can discharge. The lower border is usually determined by the dry weather flow as a minimum discharge. In case of normal weather conditions where the tanks are not filled and ADESBA is not controlling, the throttles are adjusted to a permitted throttle flow, the nominal throttle flow (Qnom). To assess the extent of influence that the throttle range has, the range of controlling around the Qnom value was varied in three spectra. These spectra were 20, 50 and 80 % valve opening/closing from the nominal throttle flow towards Qmax and towards zero discharge.

Figure 66 illustrates the ranges that were tested. Each range was applied to all tanks.

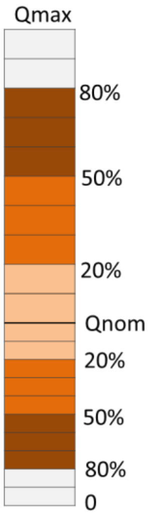


Figure 66 Throttle range, *i.e.* valve opening/closing from the nominal throttle flow towards Qmax and towards zero discharge (%).

Figure 67 to Figure 69 indicate the behavior with regard to overflow volume, counts and days. It shows that the total overflow volume is reduced with increasing throttle range. Except of the first tank at Gartenstr., the overflow volumes of all tanks are reduced or stay at the same level.

When a narrow range is set, an elongation of the periods of discharge is expected, with the result that consecutive CSO events are combined. When a wide range is set, water levels can rise and fall faster. This way, consecutive CSO events are rather separated. In the latter case, events where the water level is fluctuating around the overflow crest are likely to happen more often. Each tipping over the crest is considered as one overflow. Thus, the overflow count increases. The overflow days, however, decrease slightly. The fact that a narrower range leads to longer periods where tanks are filled does increase the likelihood of overflow due to additional small amounts of water. This can prolong CSO periods over days. With a wider range, tanks can empty faster and the likelihood of extending CSO periods decreases.

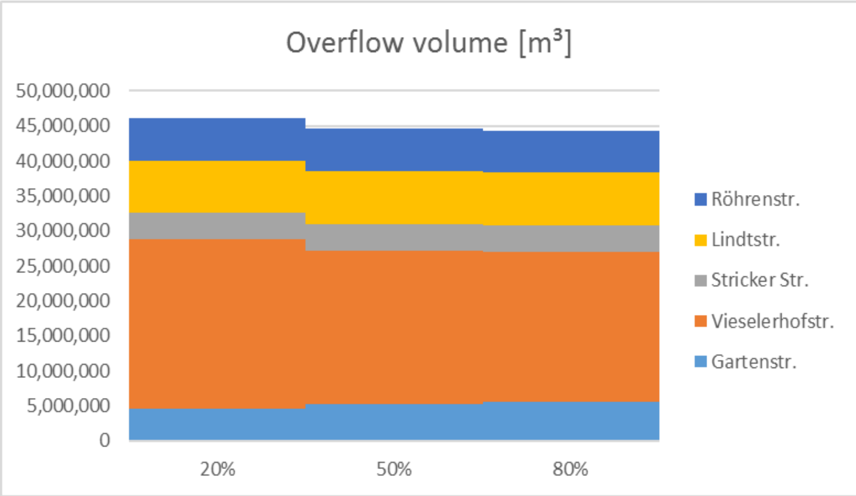


Figure 67 Total overflow volume resulting from the Simba# simulation with ADESBA in place. The throttle range in which ADESBA operates was varied from 20 to 50 to 80% of the total range between zero and Qmax. The simulations are based on 25 year MOMENT data. Different colours indicate overflow volume share of each CSO facility.

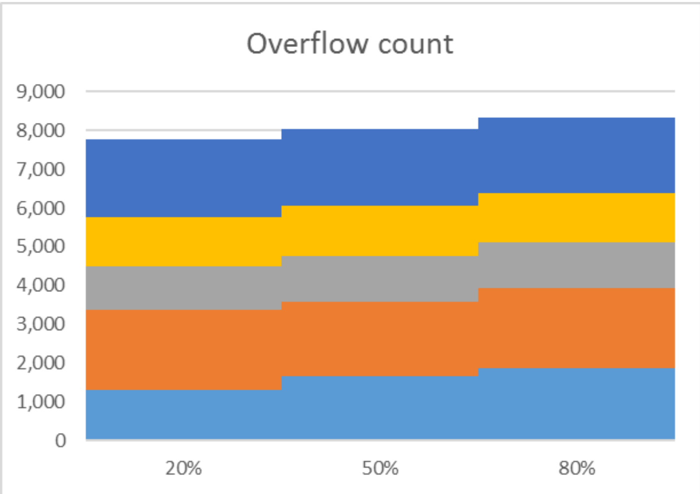


Figure 68 Total overflow count resulting from the Simba# simulation with ADESBA in place. The throttle range in which ADESBA operates was varied from 20 to 50 to 80% of the total range between zero and Qmax. The simulations are based on 25 year MOMENT data. Different colours indicate overflow volume share of each CSO facility.

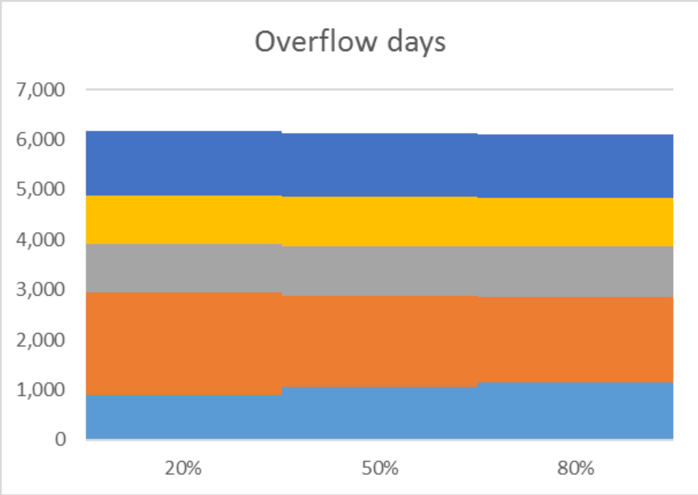


Figure 69 Total overflow days resulting from the Simba# simulation with ADESBA in place. The throttle range in which ADESBA operates was varied from 20 to 50 to 80% of the total range between zero and Qmax. The simulations are based on 25 year MOMENT data. Different colours indicate overflow volume share of each CSO facility.

A second sensitivity analysis was conducted to determine the influence of each single CSO facility within the system. In this analysis, one facility at the time was excluded from the simulation. Simulations were again based on 25 year MOMENT data. Figure 70 underlines the importance of the tank at Vieselerhofstr. Without RTC of this tank, the overflow volumes increase greatly. The tank at Röhrenstr. has the lowest impact on the system. This is probably due to the limitation of the maximum throttle flow to Qnom, as given by authorities (see sub-chaper "Approval by agency" in chapter 4.4.3.).

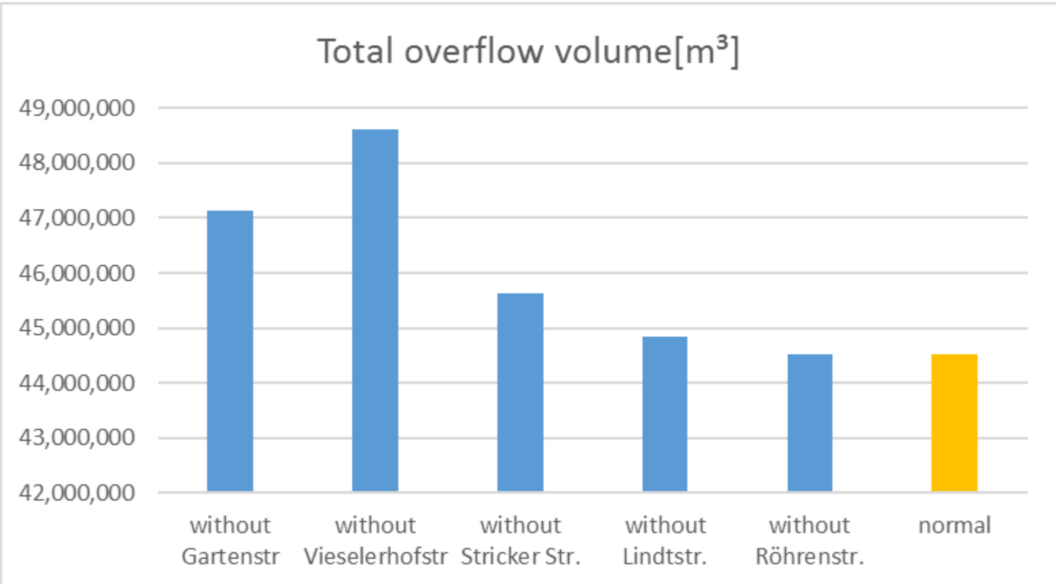


Figure 70 Total overflow volume (m^3) simulated with ADESBA based on 25 year MOMENT data. Single tanks were excluded from the ADESBA control.

A third sensitivity test was conducted to determine the effect of errors in the water level-to-storage-volume relationship due to uncertainties. Therefore, additional operators were included into the system in Simba# - this way it was possible to test wrong information.

Figure 71 exemplarily shows the water-level-to-storage-volume relationship of the tank at Vieselerhofstr. The blue line indicates the “real” condition (*i.e.* assumed to be correct) whereas the red and green lines represent an over- and underestimation. The start and end point are the same for each curve.

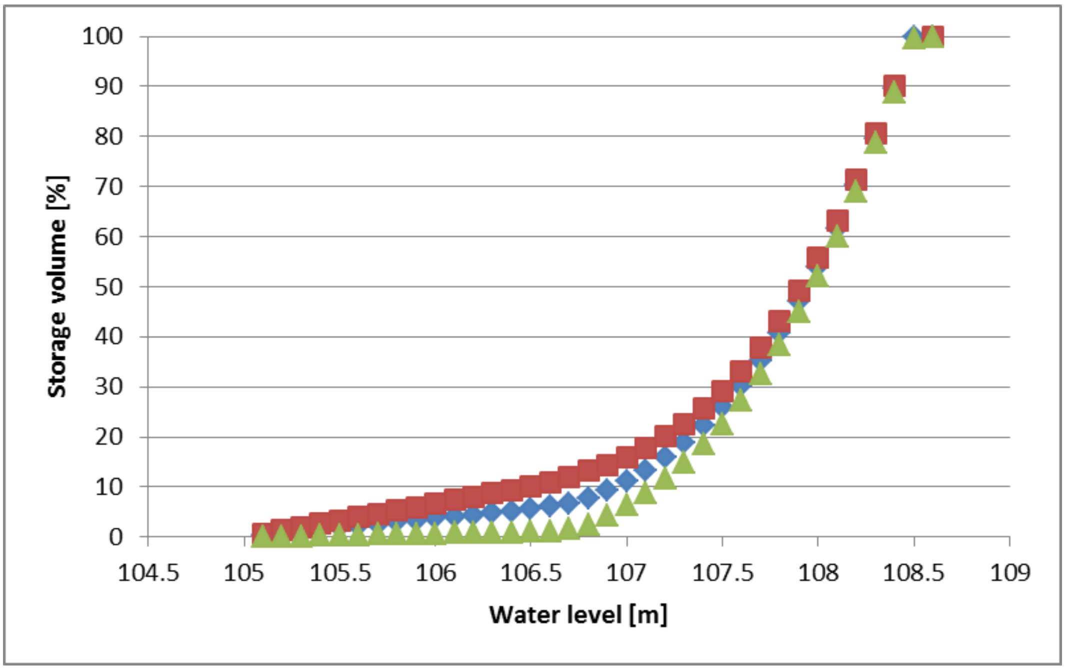


Figure 71 Exemplary scenario for over- and underestimating the water-level-to-storage-volume relationship (red and green, respectively) at CSO Vieselerstr. The blue line is indicating “real” conditions.

The under- and overrating tested at Viselerhofstr. lead only to a deviation of about 0.8 % concerning overflow volume at this tank (Figure 72). For the whole system and the total overflow, the deviation was only about 0.1 % (Figure 72).

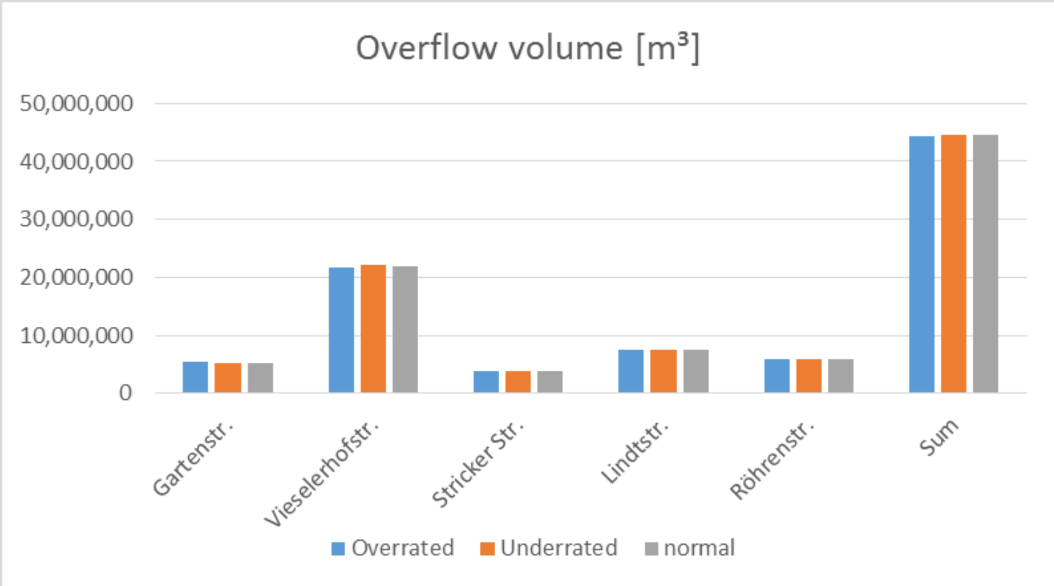


Figure 72 Overflow volume (m³) resulting from Simba# simulation with normal/"real" and over- and underestimated water-level-to-storage-volume relationships at Vieselerhofstr.

4.4.3. Technical preparations and implementation

Preparation of a planning document on the measures to be implemented: Specifications document ("Lastenheft")

The five selected CSO facilities had to be equipped with the required hardware, software and telecommunication. Furthermore, a duplication of the PLCs at the five CSOs and the adaptation of the duplicated program to ADESBA was needed. For operation, a set of security measures had to be implemented and formerly active security measures needed to continue in place. A compilation of all these due measures was brought together in a specifications document ("Lastenheft"), including also a timetable.

Preparation of a reporting document on the implemented measures: Specifications document ("Pflichtenheft" and "Globale Projektbeschreibung")

After all these measures were completed, a specifications document ("Pflichtenheft") was developed, including detailed information on each measure. This document was complemented by a detailed documentation of the telecommunication measures ("Globale Projektbeschreibung").

Re-fitting: throttle

One of the hardware re-fitting needs was to equip the 2nd discharge pipe of CSO Strickerstraße, with a throttle (Figure 73), which was formerly not needed for operation without RTC.

Figure 73 Newly installed second throttle at CSO Strickerstr.

Re-fitting: online telecommunication

An online telecommunication system had to be installed at each of the five tanks to allow minute-by-minute (real-time) data exchange between the tanks and the central office, where the WinCC-, ACRON- and ADESBA-PC are located (Figure 74).

All elements have been connected according to Figure 74 and communication was tested. A testing protocol for correct data communication has been developed by EG's department for communications engineering for this purpose. Several adjustments had to be conducted concerning correct unit transfer, optimal reporting and archiving of data. A reporting template has been elaborated for this by EG's operating department.

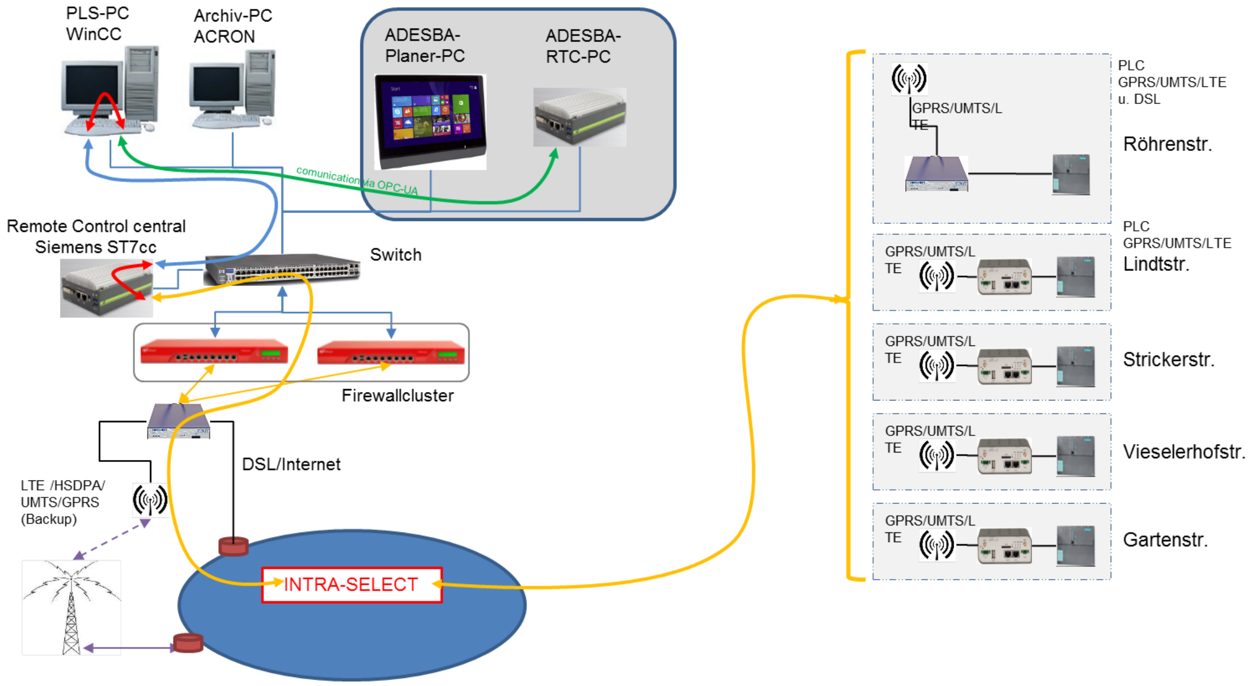


Figure 74 Communication and data transfer scheme for RTC implementation at the five CSOs.

Re-fitting: WinCC (Visualization and ACRON documentation)

The WinCC hardware and software for visualization and ACRON documentation in the central control office at Bauhof Schüren had to be updated.

Installation of ADESBA-PC

The ADESBA central control office is located at Bauhof Schüren. Here, the ADESBA-RTC-PC has been installed (Figure 75). Remote access by SEGNO has been enabled. The central control PC (WinCC-PC) at Bauhof Schüren had to be updated to allow seamless operation of ADESBA during the DESSIN testing phase and (possibly) in the future.

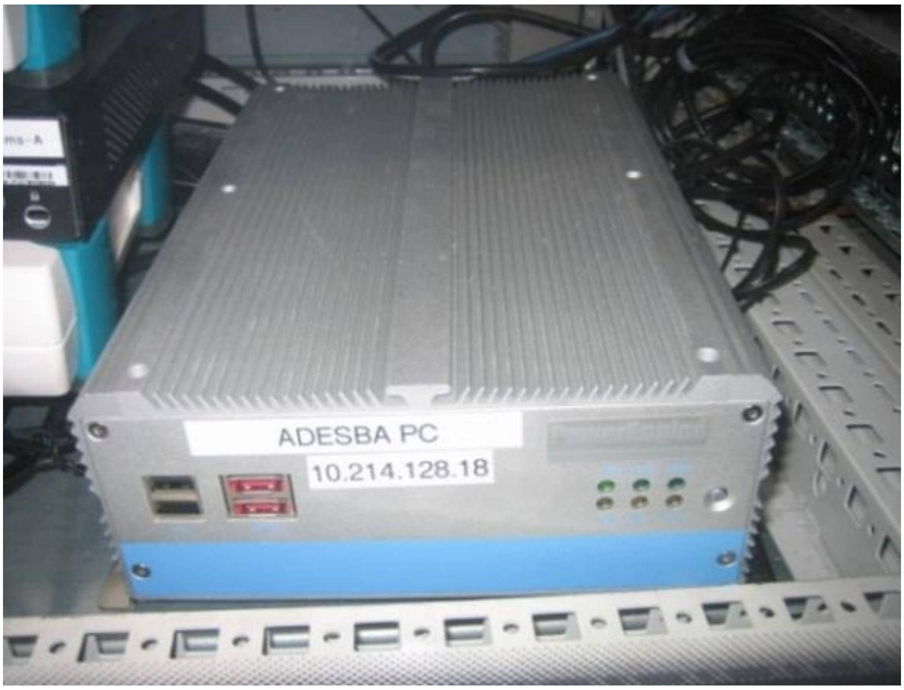


Figure 75 ADESBA-PC installed in the central control office Bauhof Schüren in Dortmund.

Setting parameters in ADESBA Planer

For each of the five CSOs, a set of parameters had to be defined as input for ADESBA. In addition to the parameters describing the CSO (Hight, volume, Qmin/nom/max, water run-time; Table 6), also the water-level-to-storage-volume relationship was to be entered here. Furthermore, some settings are defined equally for all five CSOs, these are the constants eps, eps2, beta, k, tstor and cqin as well as the control range (QNomMin/Max) (Table 8).

Programing ADESBA mode in PLCs

Each CSO has an own PLC (Figure 76), which monitors sensor measurements, controls automatic processes (such as self-cleaning processes) and allows setting parameters. A PLC program code contains all necessary demands for this.

For DESSIN, the program code of each PLC had to be adjusted. For this, the codes were duplicated at each PLC and the duplicated version was then adjusted by integrating demands required for ADESBA operation. These were demands for sending and receiving data.

Figure 76 Local control via PLC program at each CSO, here exemplarily at CSO Lindtstraße.

Which program code is read during operation - the original one ("isolated operation") or the duplicated/ ADESBA-adjusted one ("ADESBA operation") - is decided after checking if the CSO is "ready for RTC" (*i.e.* no error indication) and if one of the five CSOs has switched from dry weather to rain weather (right picture in Figure 77). Additional precondition for "ADESBA operation" is that the life signal demand ("Lebenszähler" or watch dog) from the central office receives an answer from the CSO's PLC. A timely answer indicates that data transfer runs well.

Which program is currently running is indicated in the upper left corner "ADESBA Regelung aktiv" (left picture in Figure 77).

In case the operational staff needs to conduct a routine maintenance or repair, it needs to be guaranteed that ADESBA will not become active and start controlling the throttle(s) due to a beginning rain event at this or another site. For this reason, manual intervention is enabled by selection of "ADESBA operation ON/OFF" at the PLC screen ("ADESBA-Betrieb EIN/AUS", left picture in Figure 77).

Furthermore, the PLC now displays the currently recorded values ("Ist-Werte"), such as water level, throttle setting and overflow as well as the target values desired by ADESBA ("Durchfluß-Sollwerte", left picture in Figure 77), received from the central office.

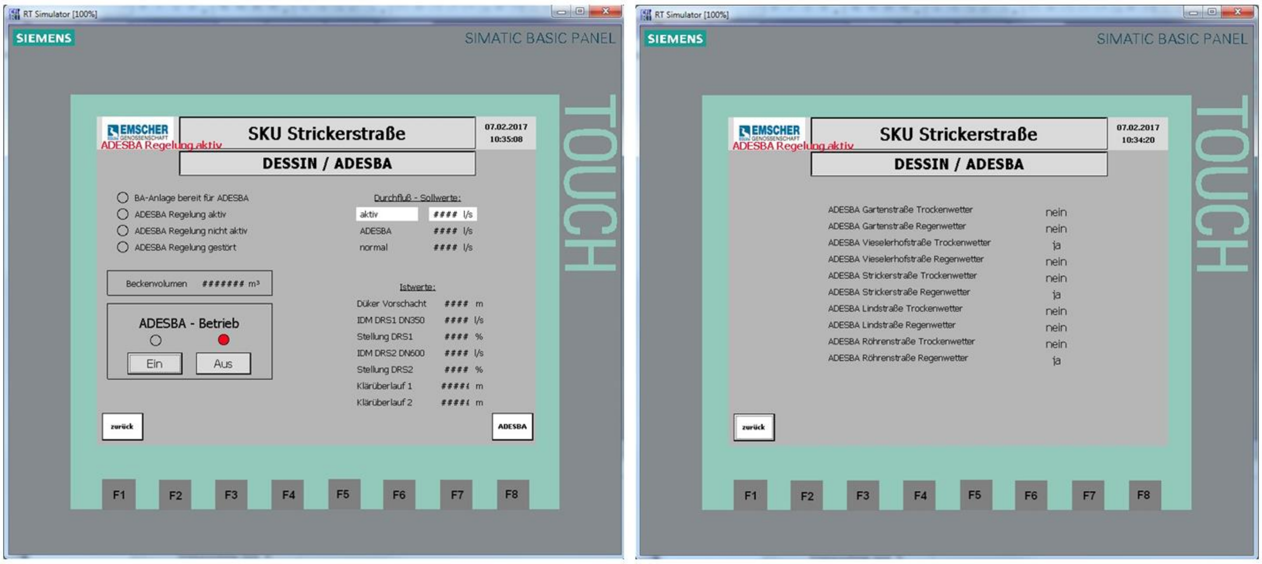


Figure 77 Adapted PLC visualization at all CSOs, here exemplarily CSO Strickerstraße.

The target throttle values desired by ADESBA are sent from the ADESBA-PC to the PLCs of each CSO, if the following preconditions are met:

- All five CSOs need to be ready for ADESBA operation (*i.e.* status „BA-Anlage bereit für ADESBA“).
- All five CSOs need to be failure-free (not “ADESBA Regelung gestört”).
- One of the five CSOs needs to have rain weather status („Regenwetter“).
- ADESBA operation is selected “ON” („Freigabe ADESBA-Regelung“) in the WinCC.

Table 12 summarizes these status notifications and their possible values.

Table 12 Status notifications of the ADESBA controlled CSOs.

Status notifications concerning ADESBA		Parameter name
ADESBAEin	1 = ADESBA-RTC active, 0 = ADESBA-RTC not active	$.RTC.ADESBAEin
ADESBAAus	Approving command for RTC operation 0 = approved, 1 = not approved	$.RTC.ADESBAAus
AutoBereit	Basin ready for automatic operation 1 = ADESBA may control 0 = ADESBA may not control	$.PLC.AutoBereit
AutoEin	1 = ADESBA-RTC active 0 = ADESBA-RTC not active	$.PLC.AutoEin

Measures for security

All water and wastewater facilities that are part of a large-scale system are considered as critical infrastructure. This means they are at risk of cyber-attacks, leading to harm at public water supply and sewage disposal. For this reason, security measures are of high importance.

For the five CSOs, a number of security measures were taken - in addition to the security measures already considered in the development of the ADESBA RTC by Segno (Milestone MS7 in WP21).

These were:

- A plausibility test (that was in place already in the un-controlled system) checks if the minimal outflow to the WWTP is guaranteed. If not the case, this indicates a blockage of the outflow pipe, which needs to be removed.
- A manual ADESBA-off button was implemented at the PLC of each CSO ("ADESBA operation ON/OFF") as well as at the WinCC in the central office.
- A switch to standard mode occurs automatically in case of error messages or communication failure.

Operational data visualization, documentation, archiving and reporting

The operational staff at the central office in Bauhof Schüren has to be able to monitor each CSO as well as the total real time controlled system at any time. So far, each CSO could only be visualized individually. Yet, in order to monitor ADESBA, a view of the total system is required. This allows understanding if the ADESBA demands and throttle adjustments are reasonable.

For this reason, the operational staff of EG has programmed a new visualization and user interface (Figure 78 and Figure 79).

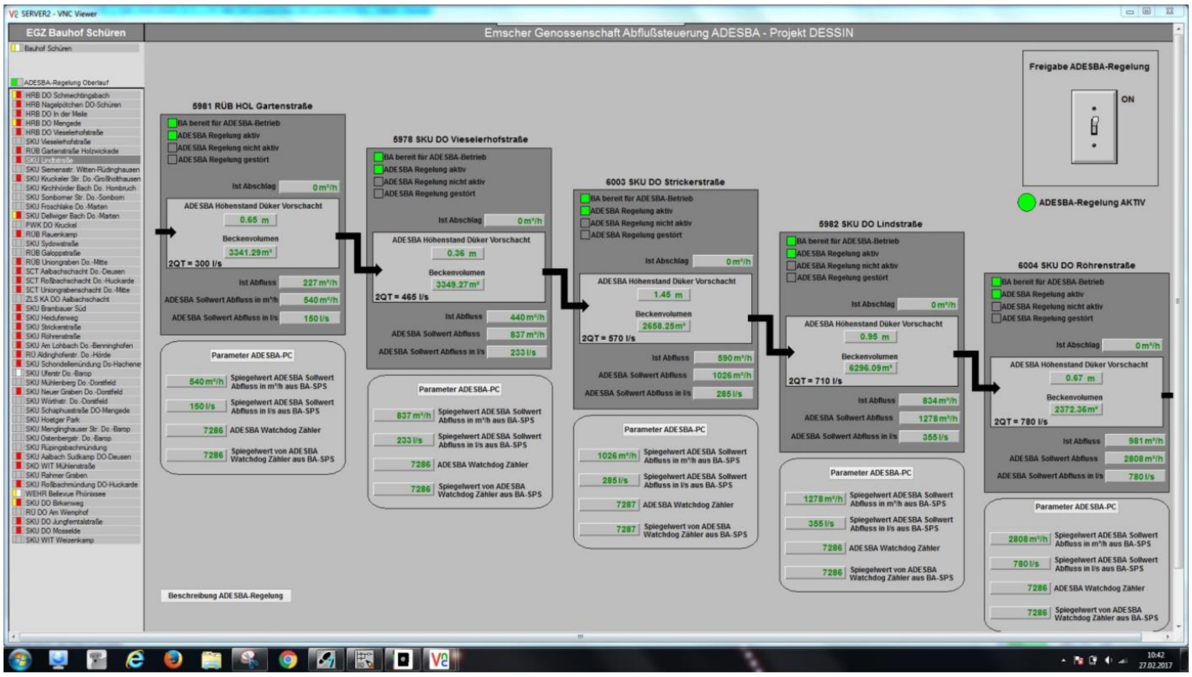


Figure 78 Newly developed overview of the total controlled system at the WinCC in the central office.

Figure 78 shows the overview of the current status of each CSO (“ADESBA” or “isolated operation” active), the current water level and outflow (in l/s and m^3/h), the response values (“Spiegelwerte”, *i.e.* reflected values) and the watch dog. Furthermore, the interface allows to manually switch to ADESBA operation (“Freigabe ADESBA-Regelung”). In case of maintenance or repair operation or any kind of risk or errors, switching off “ADESBA operation” means that “isolated operation” is activated. If “ADESBA operation” is activated and all CSOs are “ready for ADESBA operation”, a green light in the upper right corner indicates that ADESBA operation is running (“ADESBA-Regelung AKTIV”).

On the screen it is furthermore possible to open a description of the DESSIN project with all kinds of information „Beschreibung ADESBA-Regelung“ appears as a pdf-document, provided by the department of communications engineering of EG. Additionally, a parameter overview for each CSO individually can be accessed by clicking on „Parameter ADESBA-PC“ which shows the respective ADESBA parameter settings for each CSO facility (Figure 79).

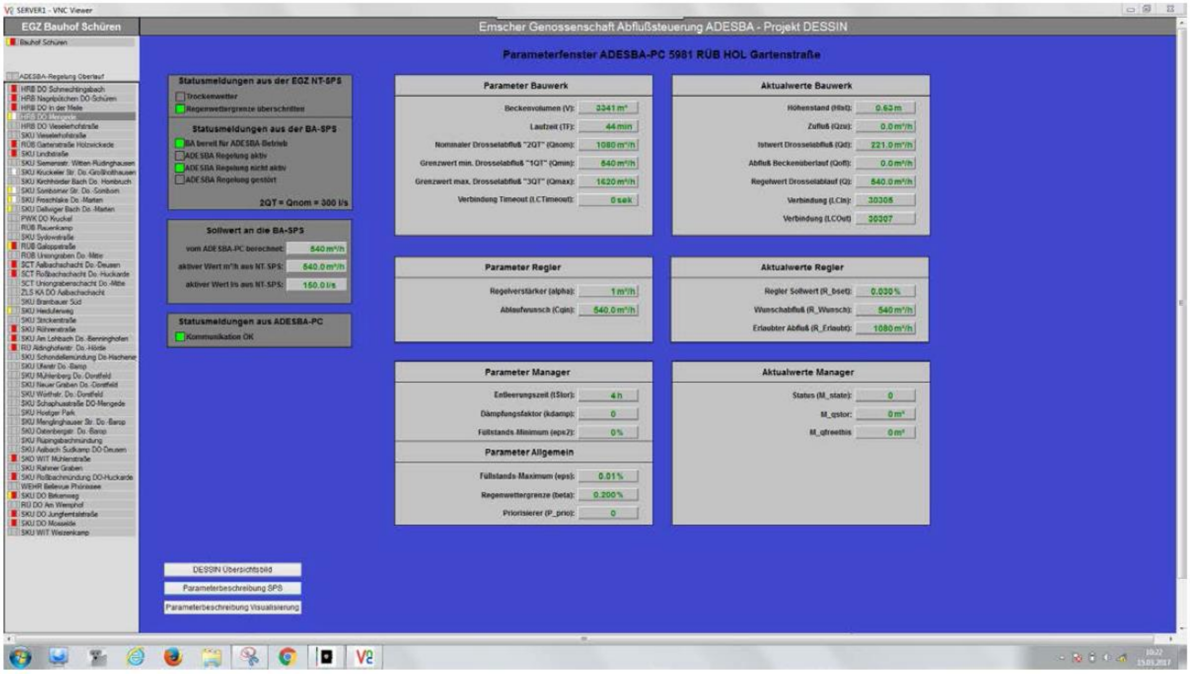


Figure 79 Parameter setting for each CSO facility visualized in the WinCC, exemplarily for Gartenstraße.

Documentation, archiving and reporting

All operational data is documented and archived in the ADESBA-PC and in ACRON. From here, they can be extracted in graphical and raw data format.

From the ACRON archive, different time periods can be plotted or raw data exported. For instance, certain hours, days, rain events, weeks, months or years can be extracted, as exemplarily shown in Figure 80. These graphical or tabular reports can be extracted for single CSOs or for the full system (Figure 80). Additionally, the overall overflow volume and count can be reported in table format.

As the report has to match to the standard reports handed over by EG to the approving agencies, all required information needs to be documented and archived. The approving agencies have to be able to reconstruct why the RTC controlled each CSO the way it did. Therefore, an overview of the total system is of high importance.

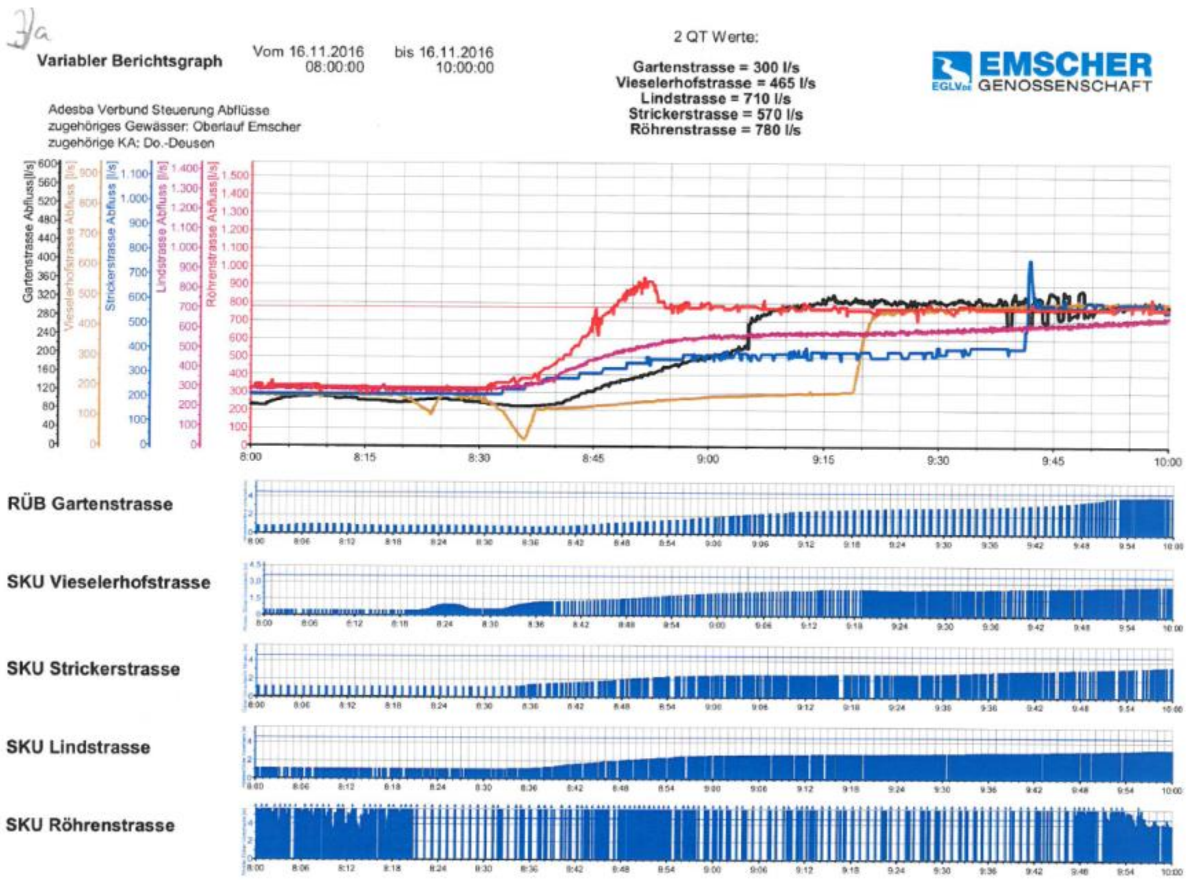


Figure 80 Exemplary report of the ADESBA controlled CSO operation for the entire system, generated via ACRON.

Approval by agency

The test operation of the ADESBA-RTC at five CSO facilities along the upper Emscher was applied for at the district council (Bezirksregierung Arnsberg). Following two meetings, the agency has given their consent to the test operation on 25th July 2016.

The following obligations have been demanded for the approval:

1. The operation has to be started within one year after approval.
2. Beginning and end of the test phase have to be communicated to the Bezirksregierung.
3. The outflow of the last CSO facility (Röhrenstraße) may not exceed the approved value of Qnom = 780 l/s.
4. The outflow of each CSO facility has to be limited to a maximum value (*e.g.* 1.5*Qnom) in order to avoid a capacity overload of the sewer network. The maximum outflow is to be communicated to the Bezirksregierung.
5. With the start of an overflow event at a CSO facility, it has to be ensured that at least Qnom

is being discharged by the throttle of this CSO facility.

6. The recorded data has to be compiled after completion of the test phase and interpreted. The knowledge gained is to be handed as a report to the Untere Wasserbehörde Dortmund.

Testing, trouble shooting and optimization phase

After all hard- and software was implemented and data transfer set up, ADESBA was activated but the target values for throttle settings that ADESBA calculated were not yet realized at the basins. This was done on purpose in order to test if values are correctly transferred from the CSOs to the central office and back and if error messages and notifications were realized.

During this period, SEGNO had remote access to the ADESBA-PC in order to update and adapt the program, check and change parameter settings in the ADESBA-Planer and check the produced target values. For reasons of safety, EG only enabled the remote access when it was needed to avoid having a constant “entry point” into the EG system.

After a short period of running ADESBA with a narrow throttle range, the range was increased to 100 % between Qmin and Qmax.

4.5. Operation

4.5.1. Exemplary results

Figure 81 visualizes the rain event on 1st September 2017. The controlling process is described exemplarily for this event in the following paragraph. The CSO facilities are numbered as follows: CSO 1 = Gartenstraße, 2 = Vieselerhofstraße, 3 = Strickerstraße, 4 = Lindtstraße, 5 = Röhrenstraße.

ADESBA starts controlling the throttles when the water level in one of the CSOs reaches 20 % of the storage volume. ADESBA stops controlling when the water level of all CSOs drops below 20 %.

During the rain event on 1st September 2017, the curves in Figure 81 show that the outflow of CSO 2 and 3 start increasing in parallel at 12:20. Thus, the rain must have started close to these two CSOs. As soon as one of the two CSOs reached a filling degree of 20 % (at 12:30), ADESBA starts controlling all five CSOs. This is indicated as “ADESBA Regelung aktiv” by the triangles and horizontal lines. In CSO 2 the outflow increases rapidly, in CSO 3, however, the outflow increases slowly. The reason might be the water run-time of approximately 13 minutes between CSO 2 and 3.

ADESBA demands the opening of the throttles in CSO 2 and 3. As a result, the water level in these two CSOs now increases less steeply. Accordingly, the water level and outflow at CSO 3 and 4 starts to increase.

At 12:35 the outflow in CSO 2 exceeds Qnom and at 12:45 the maximal water level is reached. An overflow into the upper Emscher starts. The volumes of CSO 3, 4 and 5 are not yet fully used.

CSO 1 has a strong increase in the outflow at 12:35 and again at 13:00. Now the maximum water level is reached. Because overflow is already happening at CSO 2, ADESBA cannot control CSO 1 anymore. At 13:30, overflow at CSO 1 starts.

As CSO 1 and 2 cannot be controlled anymore, the throttle in CSO 3 is being opened (13:00) in order to achieve a better water distribution with the remaining CSOs. Accordingly, the outflow in CSO 3 increases and the water level decreases. Subsequently, CSO 4 and 5 show slow increases in their water level.

Then, the water level in CSO 3 starts to rise again. ADESBA controls the CSO by opening the throttle. Thus, the outflow increases and accordingly the water level in CSO 4 and 5 increases. At 13:35 an overflow begins at CSO 3.

The throttle of CSO 5 is not controlled, because it is the last facility, *i.e.* closest to the next WWTP and the flow to the WWTP may not exceed the Qnom value.

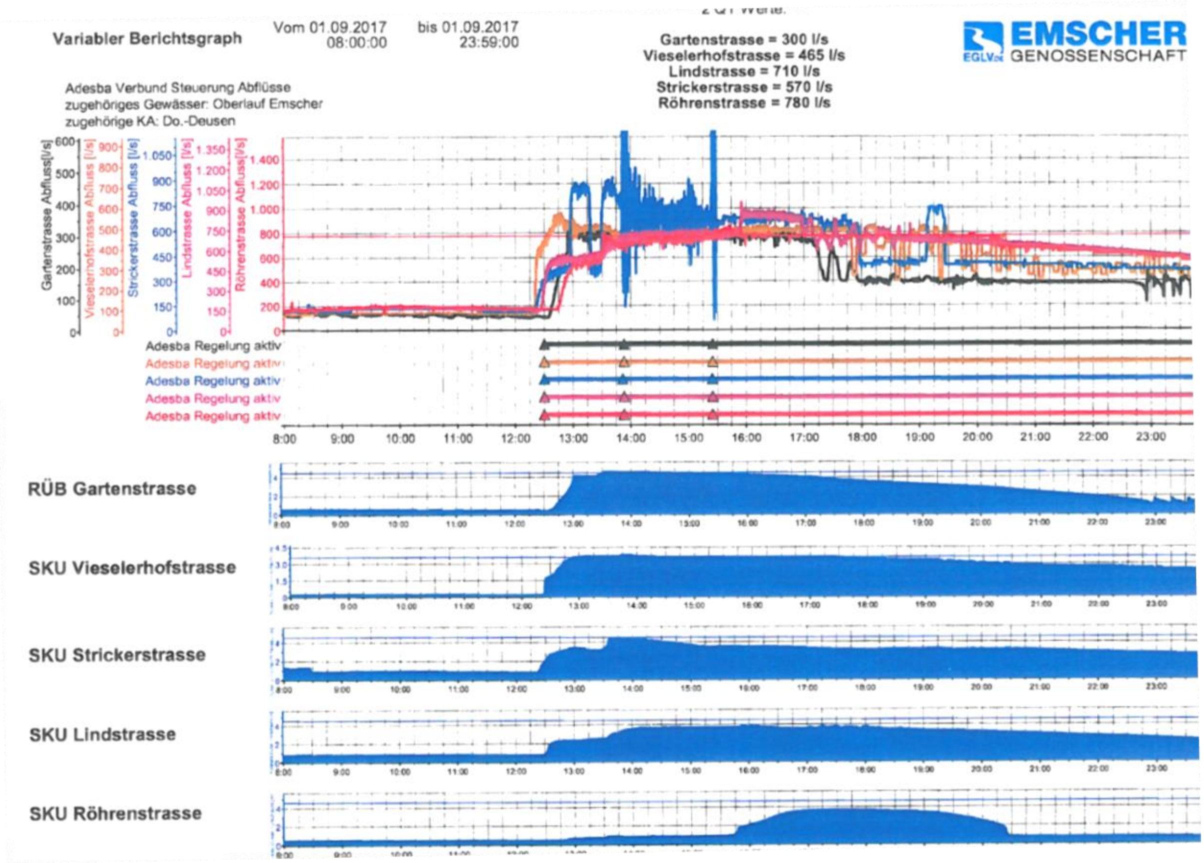


Figure 81 Graphical report from ACRON visualizing the outflow and filling level in all five CSOs on 1st September 2017.

4.5.2. Analysis of success

For the analysis of success, the following method was developed:

For each of the five tanks, operational data of throttle flow and water level was measured and recorded in one-minute steps. Based on this information, the inflow and overflow was calculated.

Since this data is based on a system operating with ADESBA, a comparison of the ADESBA controlled process (*i.e.* the course of the filling degree throughout one rain event) monitored in real operation to the same system and same rain event without ADESBA is not possible. Thus, the controlled system was simulated in Simba# (Figure 62) and then the ADESBA-derived throttle settings were backcounted to standard settings (Qnom) to simulate the simulation of the system without ADESBA. This means, the influence of the controlled throttle flows was discounted. The simulation was run for those rain events during which an overflow was detected. Calculated overflow volumes and durations with and without ADESBA were then compared. However, as the operational data with ADESBA and the simulations with ADESBA showed diverging results, the simulations without ADESBA were not compared to the simulations with ADESBA but to the operational data with ADESBA.

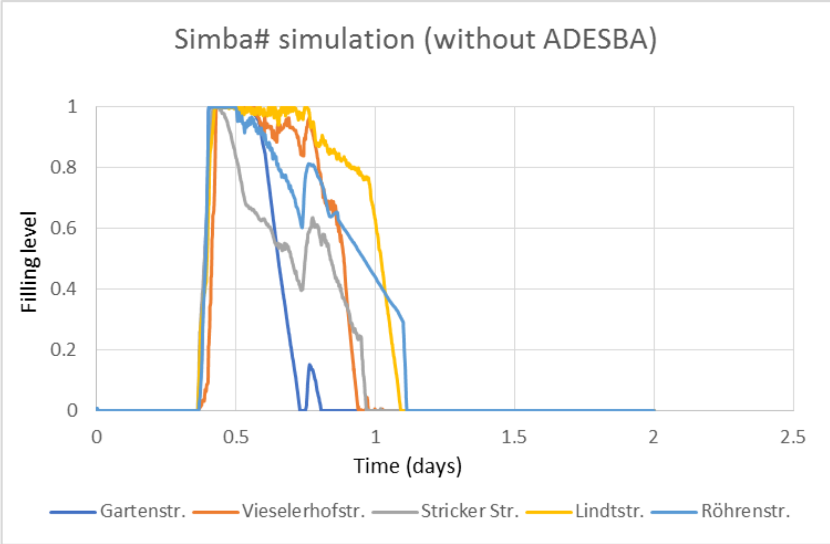
4.6. Results and discussion of test operation

The comparisons of the operational data with ADESBA and the simulations without ADESBA for various rain events show diverse results. Due to problems with the water level measurements at Gartenstr., no overflow at this tank could be detected in three rain events. The overflow at Gartenstr. could, therefore, not be considered in the assessment. However, the results (disregarding Gartenstr.) show overflow reductions of up to 42 %. In one event, however, a higher overflow volume was detected in the system with ADESBA compared to the system without ADESBA (Table 13).

Eight rain events with overflow have been recorded between July and November 2017. Out of these, four rain events have been selected for evaluation: 25.-26.7.2017, 5.-6.8.2017, 30.9.-2.10.2017 and 23.-26.11.2017. Unfortunately, in the July and August events, the water level sensor at CSO Gartenstr. was defective - therefore, the overflow volumes of CSO Gartenstr. need to be disregarded at these events.

Exemplarily, the course of the rain event at 5.-6.8.2017 is shown for the simulated case without ADESBA and the monitored case with ADESBA in Figure 82. It can be observed, that with ADESBA in place, the period at maximum filling degree (*i.e.* the tank is close to overflow or already overflowing) is shorter. Furthermore, the tanks empty more equally. A difference in the filling process cannot be observed because the rain started very abruptly at all basins.

a)



b)

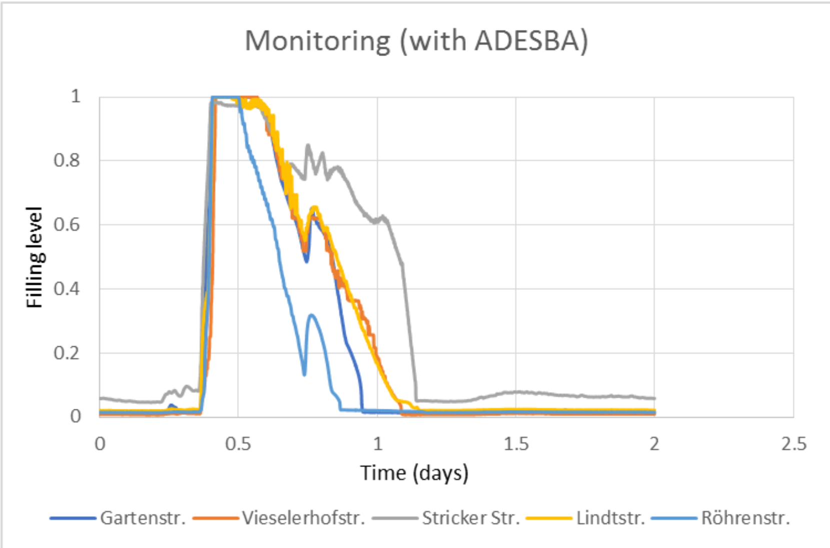


Figure 82 Filling level throughout the exemplary rain event of the 5.-6.8.2017 a) without ADESBA as simulated in Simba# and b) with ADESBA as monitored from real operation.

The difference in overflow volume between the monitoring/operation (*i.e.* "with ADESBA") and the simulation in Simba# (*i.e.* "without ADESBA") is shown in Table 13. In summary, the following reductions in the overflow volume were determined during four rain events: 37.3, 19.1, -16.6 and 31.5 %. It has to be noted that the rain event 30.9.-02.10. 2017 was rather a small overflow event.

Table 13 Overflow volume in the real operation (*i.e.* "with ADESBA") and the simulation in Simba# (*i.e.* "without ADESBA"). Red = Gartenstr. not considered in the calculation of total overflow volume and overflow time due to a failure in monitoring.

Date	CSO facility	Overflow volume		Overflow time	
		Monitoring (= with ADESBA) [m^3]	Simulation (= without ADESBA) [m^3]	Monitoring (= with ADESBA) [h]	Simulation (= without ADESBA) [h]
25.-26.07.	Gartenstr.	572	0	0.2	0.0
	Vieselerstr.	17009	15380	9.0	10.1
	Strickerstr.	1789	204	2.5	0.6
	Lindtstr.	5497	27120	4.5	15.1
	Röhrenstr.	8980	11250	8.3	11.0
	Sum	33846	53954	24.4	36.7
		Total overflow volume reduction	**37.3 %**	**Total overflow time reduction**	**33.7 %**
05.-06.08.	Gartenstr.	0	303	0.0	0.6
	Vieselerstr.	3931	2496	1.5	2.9
	Strickerstr.	735	482	1.0	0.6
	Lindtstr.	2301	6070	1.2	2.9
	Röhrenstr.	3347	3699	2.3	2.3
	Sum	10313	12747	6.0	9.3
		Total overflow volume reduction	**19.1 %**	**Total overflow time reduction**	**30.3 %**
30.09.-02.10.	Gartenstr.	0	0	0.0	0.0
	Vieselerstr.	1255	1121	2.2	2.2
	Strickerstr.	0	0	0.0	0.0
	Lindtstr.	667	342	1.1	0.9
	Röhrenstr.	1909	1822	3.2	3.0
	Sum	3831	3285	6.5	6.1
		Total overflow volume reduction	**- 16.6 %**	**Total overflow time reduction**	**-5.7 %**
23.-26.11.	Gartenstr.	3686	3801	3.08	5.6
	Vieselerstr.	4187	4197	3.67	4.7
	Strickerstr.	415	2941	0.90	2.4
	Lindtstr.	1780	8669	1.82	7.3
	Röhrenstr.	6771	4958	7.20	5.9
	Sum	16840	24566	16.67	25.94
		Total overflow volume reduction	**31.5 %**	**Total overflow time reduction**	**35.7 %**

At this point, the results are still preliminary due to the relatively low number of rain events evaluated. Furthermore, uncertainties concerning the accuracy of the measurement and the simulation exist. Nevertheless, the results show the clear tendency that the ADESBA system works as it should, *i.e.* that the overflow volume can be reduced by implementing the ADESBA control.

Uncertainty

- As the analysis of potential, which was conducted before implementation of ADESBA in reality, predicted lower reduction efficiencies, further validation is still needed by analyzing more rain events.
- The ADESBA algorithm in the ADESBA-PC and in Simba# do not deliver the same output on the calculated inflow, water level and the targeted throttle setting. The reason is not yet clear. Time steps between the data points are not diverging, as they are 1 minute both in the ADESBA-PC and in Simba#. However, the aggregation is different and hinders comparability. In Simba#, data points are simulated in 1 minute steps, but then averaged over 10 minutes for evaluation, as no severe difference due to this aggregation was apparent. In the ADESBA-PC, data are recorded and archived in 1 minute steps. In ACRON, demanded throttle settings are recorded every minute but averaged over 5 minutes. For each parameter, data points are archived only at those time points when changes occur.
- For the analysis of success, it was planned to retrospectively simulate ADESBA controlled events also in Simba#. This is possible by counting back the ADESBA controlled throttle settings to standard settings (Qnom). However, the filling degrees determined for the controlled case in Simba# (applying the same inflows derived from the monitoring) deviates from the filling degrees monitored in reality. Even when applying the monitored (*i.e.* RTC-controlled) throttle flows instead of simulated throttle flows, the filling behavior of the tanks deviated from the monitored filling levels. The reason for this deviation still needs to be identified. This uncertainty needs to be acknowledged when modelling the system. For this report, the overflow behavior of the simulation without ADESBA was, thus, compared to the ADESBA controlled events monitored in reality instead of the simulation with ADESBA.

4.7. Upscaling

4.7.1. Potential for the whole Emscher catchment

The main aim of this demonstration case was the testing and implementation of the ADESBA-RTC system in a manageable and reasonable dimension. Therefore, the system was tested at only five facilities. To get an impression of the benefit the ADESBA system could provide on a larger scale, the algorithm was also tested by simulation of the whole sub-catchment of the WWTP Dortmund Deusen. Here, the combined sewer network runs in parallel to the upper Emscher and, thus, CSO facilities discharge into the upper Emscher or the Emscher tributaries in case of heavy rain events. The sewer system including 36 storage structures was transferred into Simba#. The network structure was quite complex with the 36 tanks connected in series and in parallel (Figure 83). The upscaling of the potential overflow reduction by using ADESBA was, thus, conducted based on these 36 CSOs. One fictive CSO just before the WWTP had to be added to the modelled network for sake of running the Simba# model.

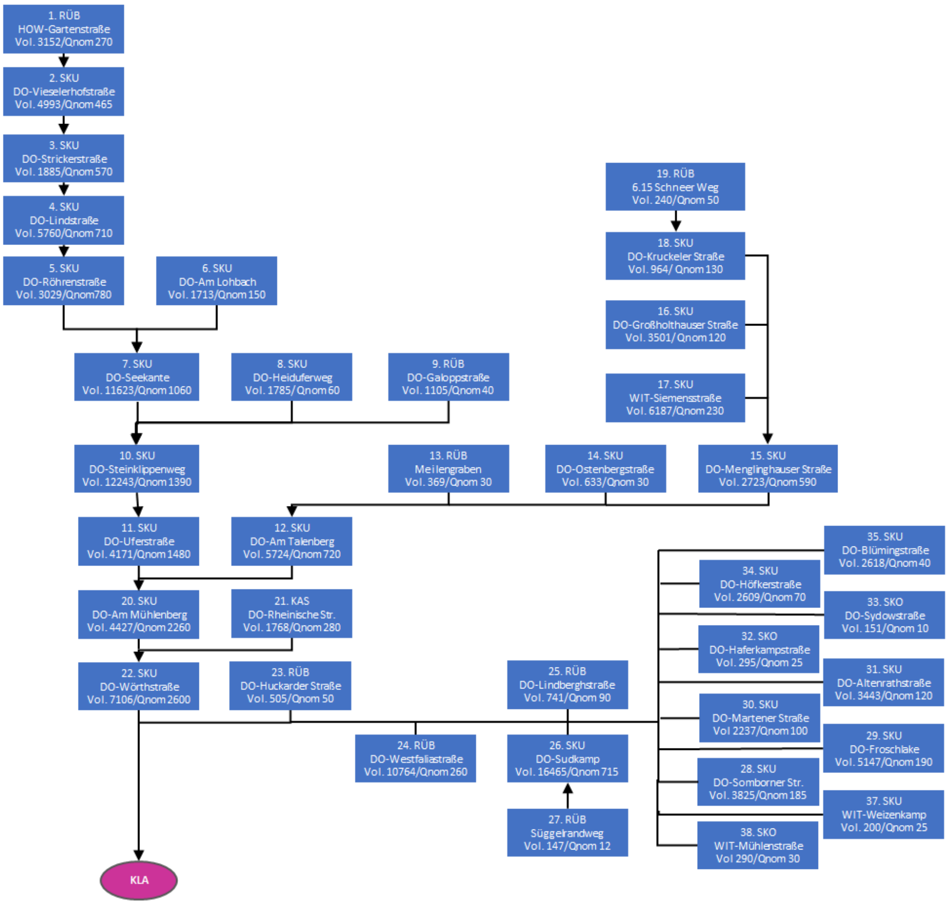


Figure 83 Sewer network of the whole sub-catchment of the WWTP Dortmund Deusen.

Information on storage volumes, throttle flows, flow times etc. were transferred from the pollution load model MOMENT, which is applied at EG, into Simba#. For the five real-time controlled CSOs, the transferred storage volumes from the MOMENT model had been refined. For the analysis of potential of the entire sub-catchment, however, the maximum storage volume for each of the 36 facilities was exclusively taken from the MOMENT model, also for the five real-time controlled CSOs.

For the analysis of potential, the simulations were based on discharge data of 10 years (2006-2015).

Model structure in Simba#

Figure 84 and Figure 85 illustrate the model structure in Simba#. The system was built in Simba# according to layout drawings of the catchment.

In a second step, the ADESBA controllers were integrated into the system. Due to the complexity and the high number of parallel connections, the existing controller for Simba# had to be adjusted and updated. The ifak provided the UDE with the adjusted controllers on request. The range of throttle settings was the same as for the five controlled CSOs. The minimum throttle flow was equivalent to 0.5 times the nominal (permitted) throttle flow. The maximum was 1.5 times the nominal throttle flow. Hydrograph data representing rain water run-off from impervious areas and incoming sewers were taken from the MOMENT model, provided by EG.

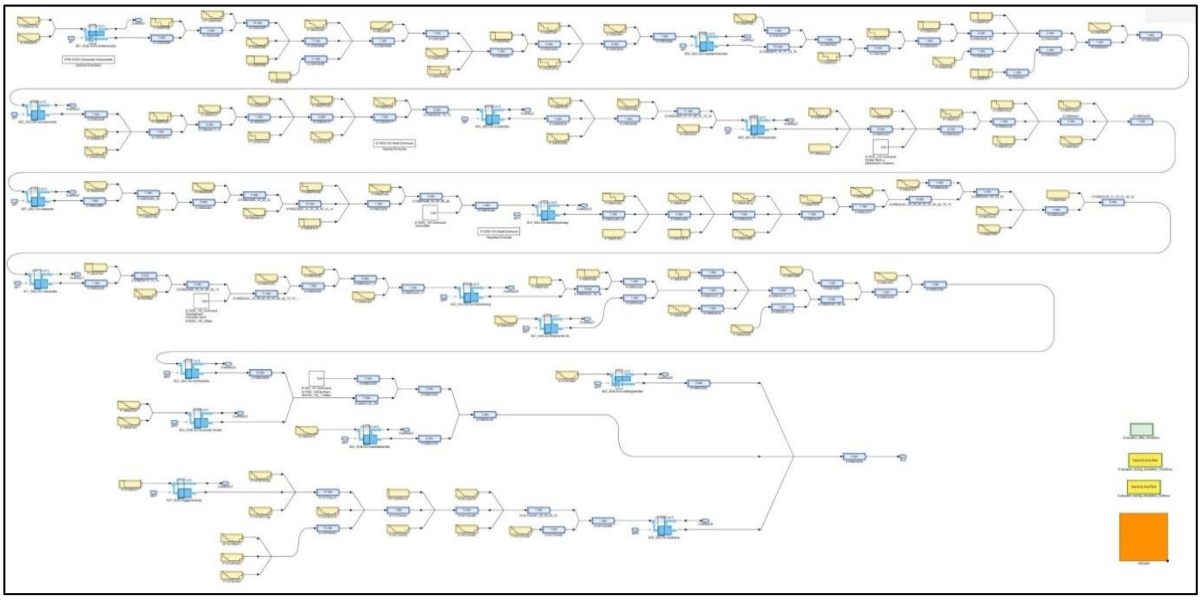


Figure 84 Overview of the 36 CSO facilities of the entire sub-catchment of the WWTP Dortmund Deusen modelled in Simba# (note that not all sub-catchments are depicted in this layer).

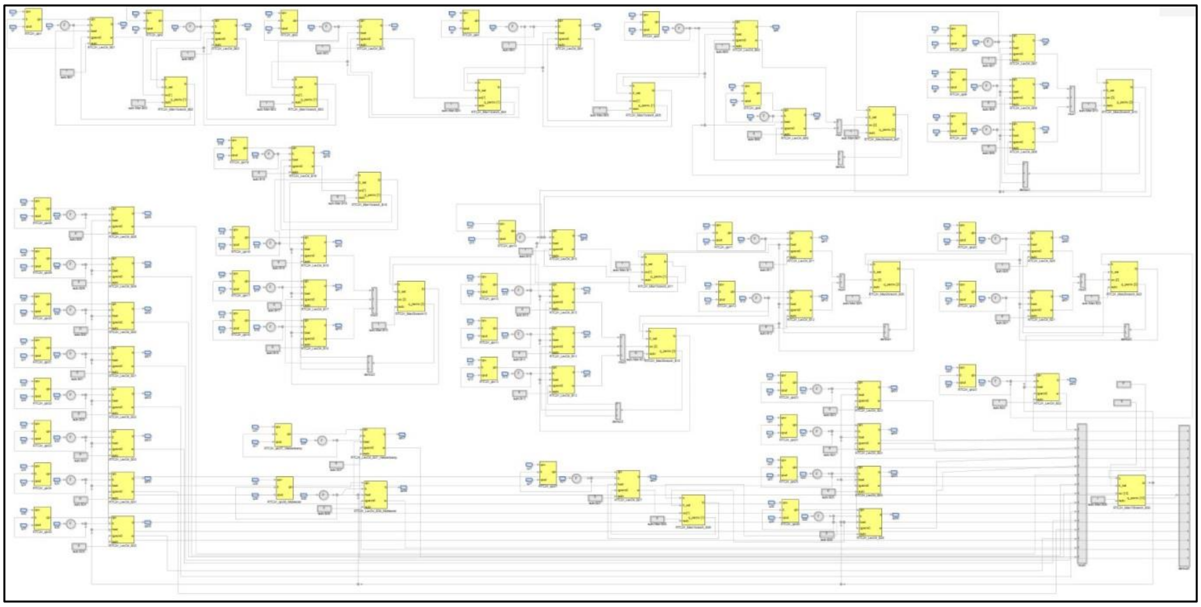


Figure 85 Overview of the underlying ADESBA control system of the entire sub-catchment of the WWTP Dortmund Deusen modelled in Simba# (note that not all sub-catchments are depicted in this layer).

To compare the result of the ADESBA simulations of the entire sub-catchment with the theoretically achievable optimum in the system, simulations applying the central basin approach have been carried out as well. This approach combines all available storage volumes of the 36 facilities in one single fictitious tank. All incoming discharges in the catchment are transported to and retained in this fictitious tank. Therefore, the total storage volume in the catchment is utilized for all incoming water. This approach is only achievable in theory. Nevertheless, the results give an impression on how well the implemented/simulated RTC works in relation to this theoretical maximum.

Results

a) **all CSOs real-time controlled**

The output of the simulations for the 10 year period shows different behaviors of each tank regarding overflow volume. For 30 out of the 37 tanks, a reduction of overflow volume was recognizable with ADESBA. For seven tanks, however, the overflow volume increased with ADESBA compared to simulations without ADESBA. Figure 86 shows the comparison of the overflow volumes with and without ADESBA for each tank for the 10 year period.

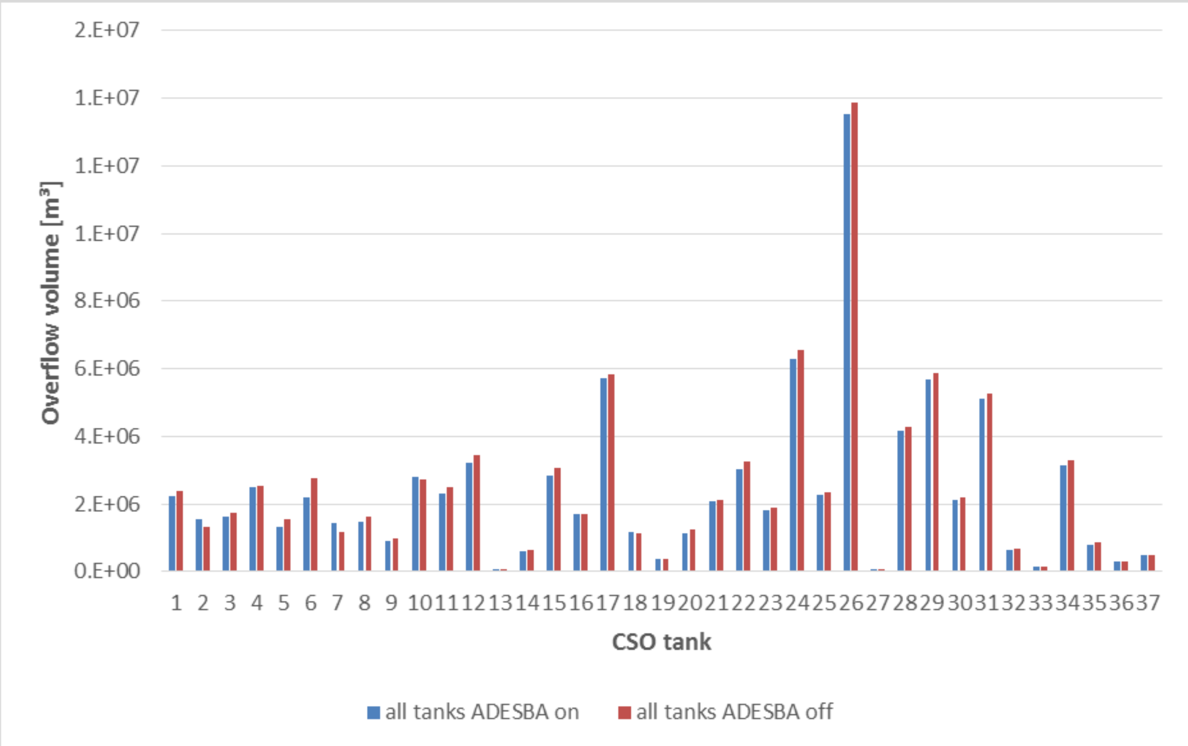


Figure 86 Overflow volumes (m3) with and without ADESBA for a 10 year period for each of the 37 CSO tanks.

The histogram in Figure 87 indicates the overflow volume behavior with ADESBA.

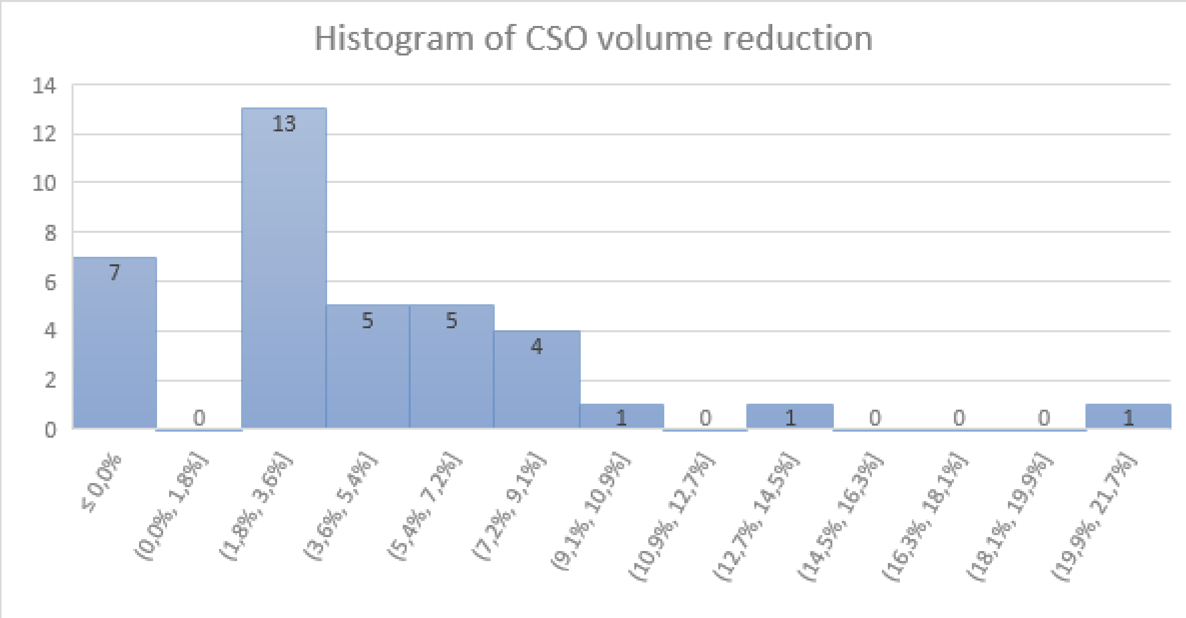


Figure 87 Frequency of reduction rates (regarding overflow volume) (%) for the 37 tanks in the catchment with ADESBA compared to the system without ADESBA.

The total reduction of overflow volumes for the whole real time controlled catchment has been identified with 3.8 % compared to the non-controlled catchment (Figure 88). The central basin approach provided a theoretical reduction of 18.6 %. The difference between both approaches (14.8 %) indicates that there might be further potential for controlling. This could be achieved by further specifying tank and catchment characteristics for the model or adjusting control parameters.

Concerning overflow days and overflow counts for of the system the total results are shown in Figure 89 and Figure 90. For the overflow days, a reduction of 6.5 % could be observed. The overflow counts were reduced by 3.4 %.

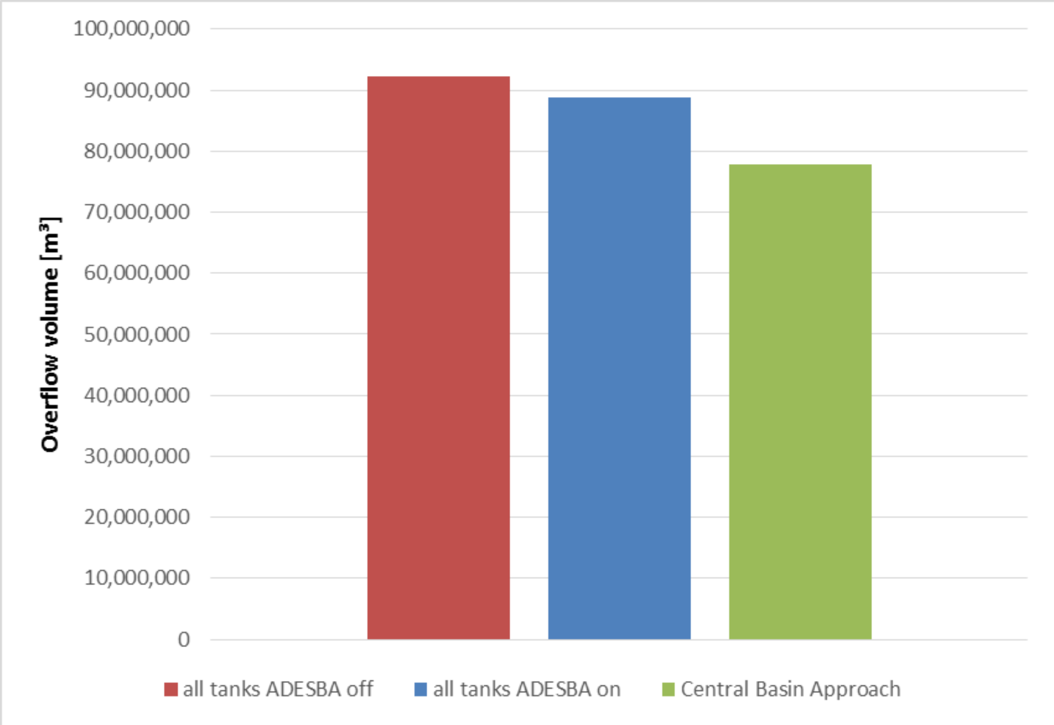


Figure 88 Total overflow volumes for a 10 year period. Results for the whole catchment with and with ADESBA are compared to the central basin approach (theoretical optimum).

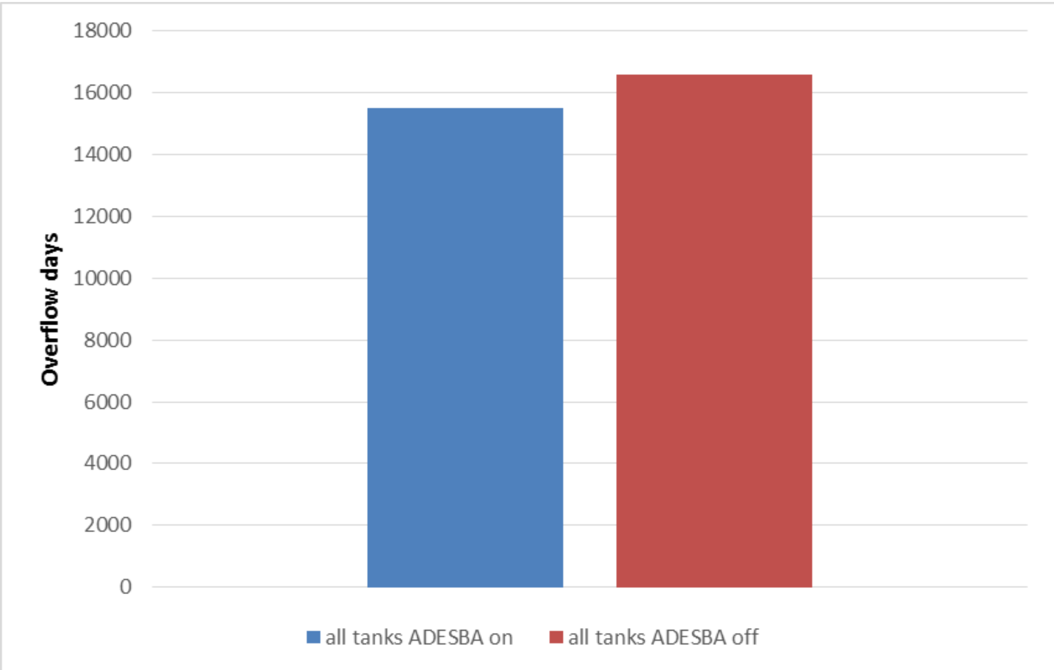


Figure 89 Total overflow days for a 10 year period. Results for the whole catchment with and with ADESBA control.

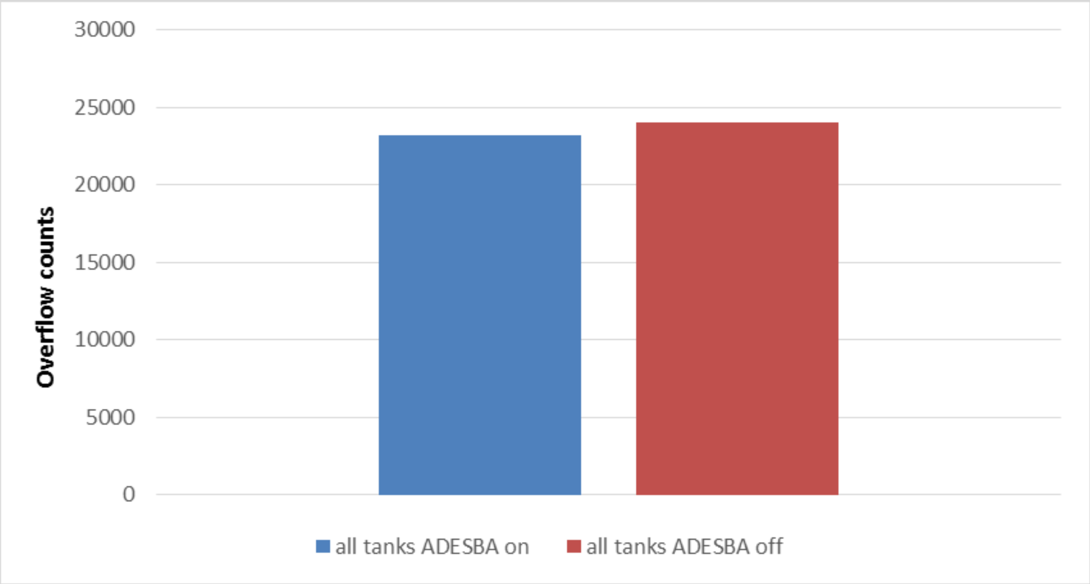


Figure 90 Total overflow counts for a 10 year period. Results for the whole catchment with and with ADESBA control.

b) only four CSOs real-time controlled (scenario no. 15)

After simulating the potential overflow reduction for the entire sub-catchment of the WWTP Dortmund Deusen, various combinations of a reduced number of controlled tanks were tested - in total 20 different combinations. An exemplary combination is illustrated in Figure 91. If a high efficiency can be obtained with a lower number of controlled tanks, the investment and operating costs would be lower. Test runs for 10 years of operation have been carried out for the different combinations. When referring to the whole sub-catchment level, the highest efficiency with regard to the overflow volume is achieved with all tanks real-time controlled. When comparing only between the tanks that apply ADESBA, the best efficiency achieved is around 7.5 % (Figure 92).

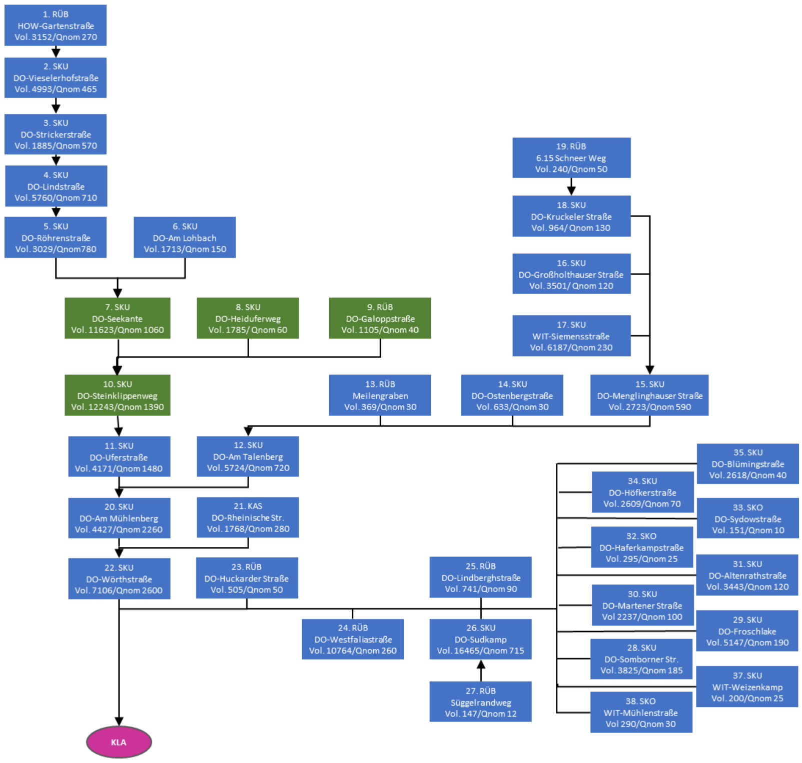


Figure 91 Example of tank combination no. 15 for real time control within the sub-catchment of the WWTP Dortmund Deusen. Green tanks are selected for control with ADESBA.

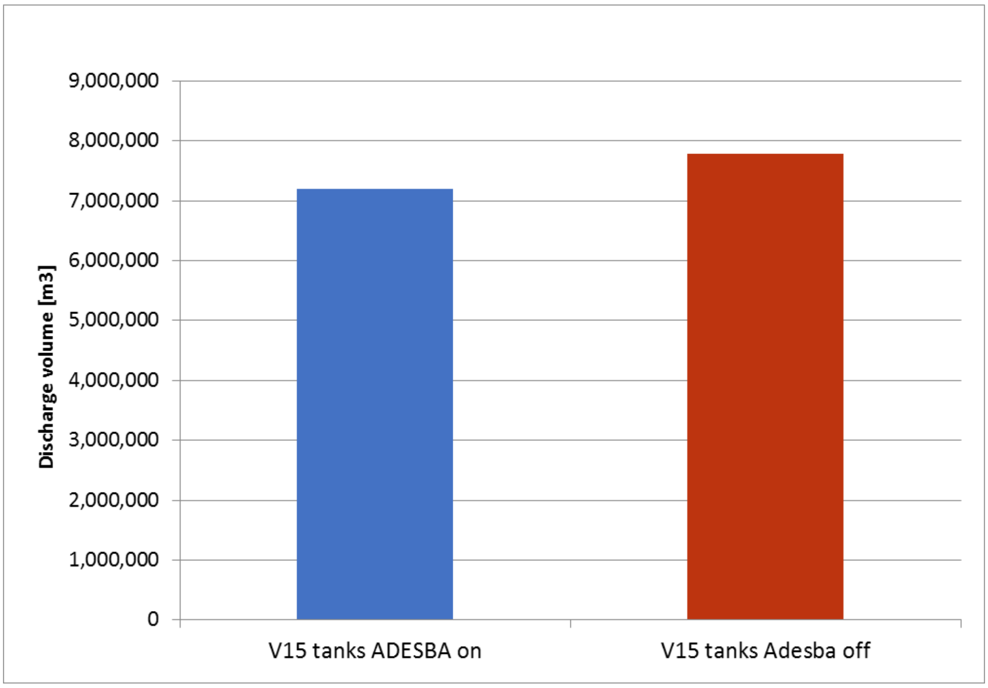


Figure 92 Total overflow volumes for a 10 year period. Results for four controlled CSOs in the catchment (scenario no. 15) with and with ADESBA.

4.8. Conclusions

4.8.1. Efficiency

Summarizing, the efficiency of the ADESBA-RTC was determined in different ways, resulting in different outcomes:

- First, the simulation of the five facilities as part of the analysis of potential estimated a potential of 7.8 % reduction in overflow volume.
- Second, in the test phase of the five facilities applying ADESBA RTC in practice. By an analysis of success, the monitored overflow behavior (volume and duration) was compared to overflow behavior simulated in Simba#, which calculates the situation without ADESBA. Efficiencies of -16.6 to 37.3 % reduction in overflow volume were detected.
- And last, the analysis of potential, simulated in Simba# for the entire sub-catchment of the WWTP Dortmund Deusen predicted a reduction in overflow volume of 3.8 to 7.5 %.

All results should be considered preliminary. The diverging outcomes of the different ways of efficiency assessment are related to uncertainties in the model. Further monitoring of additional rain events in practice is needed as well as a further improvement of the model, so that it can simulate the un-controlled condition as well as possible. A model can, however, hardly reflect reality in a precise way.

The reason for a relatively small reduction of total discharge volume per year, as predicted by the analysis of potential, is possibly that the heavy rain events - despite occurring rarely - contribute most to the overall volume. During heavy rain events, however, when the entire system is completely filled, the room for maneuver of a RTC is relatively small.

The test phase showed that discharge volumes are reduced. For this reason, one can expect that loads of particles, organic carbon, nutrients, etc. is discharged into receiving streams from CSO facilities are reduced as well. A linear correlation between volume and load reduction can be assumed, resulting in load reduction in the range of 3.8 to 37.3 % (according to the range of overflow volume reduction). This prediction is of relevance for the follow-up report, D31.2. It can be further expected that the first flush is reduced. However, uncertainty remains on this topic and would need to be addressed in future research with a specific focus on load assessment.

4.8.2. Practical experience with test operation

The practical implementation was laborious and required input from various departments of EG (coordination, water management, operational department, telecommunication department), as well as external contractors (refitting of hard- and software, development of the specification documents (“Lastenheft” and “Pflichtenheft”), programing of the PLC), support by ifak, extended simulation work by UDE, implementation of the ADESBA-PC, parameter setting and data export by

SEGNO. Furthermore, a period of trouble shooting and optimization was required, including correction of data transfer errors (unit errors), the archiving of further variables of relevance, fixing of water level sensors and the adjustment of the controlling interval to 5 minutes to reduce the over-use of the throttle valves.

The implementation of the system was quite intensive in terms of working time and investment costs. As this was the first time that ADESBA was implemented at EG, the effort was probably higher than it will be in case of future implementation or extension of the system. Nevertheless, increased personal capacity will be required during the implementation phase.

The EG staff was trained alongside the planning and implementation phase by knowledge exchange within DESSIN and by experience gained through the implementation. The EG staff was well capable of monitoring the RTC operation and detecting errors via the newly generate visualization interfaces of the entire real-time controlled system (Figure 77 to Figure 81).

No enhanced cleaning requirements appeared through the RTC.

4.8.3. Recommendations

- A manual intervention by the operating staff needs to be possible at any time.
- A fallback into local control needs to occur in case of error massages, communication failure, etc.
- The operational user interface must be easy to understand so that skilled workers can handle the system also at night time without assistance.
- The RTC can only be optimized based on the experience gained from real operation.

4.8.4. Outlook

The issues addressed in sub-chapter “Uncertainty” in chapter 4.6. will need to be resolved in follow-up work on the case study. One of the main issues is to harmonize the ADESBA calculations in ADESBA-PC and Simba# in order to deliver the same output on the calculated inflow and the targeted throttle setting.

Furthermore, the following optimizations and further tasks should be addressed in future research:

- An elongation of the testing period is desired by all partners. A continuation of the ADESBA operation is already accepted by the approving agency.
- The analysis of potential for the entire sub-catchment of the WWTP Dortmund Deusen needs to be elaborated.

- This will indicate if an extension of ADESBA including further facilities makes sense. As investment and operational costs should be kept low, the focus on those CSO facilities that - when controlled jointly - have the highest potential, is recommended.
- It is to be discussed, if a potential prioritization of especially sensitive stream sections is meaningful in the sub-catchment of the upper Emscher.
- An overflow load monitoring of the CSO would improve the information basis for effect assessment. By such monitoring, the real overflow load would be available instead of the modelled loads, which are calculated based on standard concentrations. Such monitoring would also bring information on the occurrence of first flushes.
- In order to detect ecological effects, long-term biological monitoring in the streams is required. The upper Emscher, however, already reached a good ecological potential. Thus, detecting a significant effect of the RTC is improbable in these waters. When the RTC is implemented in rather degraded tributaries of the Emscher, a positive effect might be detectable through biological monitoring.
- To ease the evaluation of rain events in the future, an automated link between the ADESBA simulation in Simba# and the pollution load model MOMENT applied at EG would be helpful.
- The modelling needs to be supplemented by models on sedimentation and degradation processes in order to meaningfully assess effects.

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The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039
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