*Conference on Modelling Fluid Flow (CMFF'25)*
*The 19th International Conference on Fluid Flow Technologies*
*Budapest, Hungary, August 26 - August 29, 2025*

# MINIMIZING SEDIMENTATION IN ROUND WASTEWATER PUMPING STATIONS WITH THE ASSISTANCE OF PHYSICAL MODELS

Tim NITZSCHE[1], Horst BAXPEHLER[2], Paul Uwe THAMSEN[3]

[1] Corresponding Author. Chair of Fluid System Dynamics, Faculty of Mechanical Engineering and Transport Systems, Technische Universität Berlin. Straße des 17. Juni 135, 10623 Berlin, Germany. E-mail: tim.nitzsche@tu-berlin.de
[2] Sewer operation, Erftverband, Am Erftverband 6, 50126 Bergheim, Germany E-mail: horst.baxpehler@erftverband.de
[3] Chair of Fluid System Dynamics, Faculty of Mechanical Engineering and Transport Systems, Technische Universität Berlin. Straße des 17. Juni 135, 10623 Berlin, Germany. E-mail: paul-uwe.thamsen@tu-berlin.de

## ABSTRACT

Wastewater pumping stations play a crucial role in modern sewage systems by transporting wastewater from lower to higher elevation areas, ensuring a continuous flow to the following pumping stations or treatment facilities. These stations are vital for preventing blockages, overflows, and health hazards associated with untreated sewage. They help maintain the efficiency of sewage systems, safeguarding both public health and the environment.

However, several challenges surround wastewater pumping stations. These stations are frequently susceptible to clogging due to debris, grease, and non-biodegradable materials, which can disrupt their operation. In addition, suction chambers that tend to accumulate extensive sedimentation deposits have to be cleaned more frequently, which requires additional personnel and results in high costs.

In the presented paper, a planned suction chamber concept is scaled using hydraulic similarity principles using the Froude number and checked for its susceptibility to sedimentation. Subsequently, optimisation cycles are carried out in order to minimize the sedimentation that occurs. In the course of this process, inlets, pumps, intake manifolds, sloped walls, among others are analysed and modified with regard to the DWA 120 – „Pumping systems outside of buildings". The average sedimentation in the suction chamber was significantly reduced in the course of this project.

**Keywords: physical model, pumping station, sedimentation, wastewater**

## NOMENCLATURE

| | | |
|---|---|---|
| $d$ | $[mm]$ | Particle size |
| $Fr$ | [-] | Froude number |
| $Q$ | $[m^3/s]$ | flow rate |
| $Re$ | [-] | Reynolds number |
| $T$ | $[s]$ | time |
| $v$ | $[m/s]$ | velocity |
| $We$ | [-] | Weber number |
| $\nu$ | $[m^2/s]$ | kinematic viscosity |
| $\rho$ | $[kg/m^3]$ | density |
| $\sigma$ | $[N/m]$ | surface tension |

**Subscripts and Superscripts**

| | |
|---|---|
| A | Average |
| M | model |
| MAX | Maximum |
| O | original |
| P | Peak |

## 1. INTRODUCTION

The coordinated removal of domestic and industrial wastewater and its subsequent treatment is a vital contribution to both public health and a responsible treatment of the environment. An undisturbed wastewater transport through the sewer systems to the treatment plant plays a crucial role in maintaining this flow. Essential components in this system are wastewater pumping stations, which can be used to transport wastewater from the incoming free-flow sewer via pressure pipes to elevated regions. However, due to the high proportion of solids in the composition of wastewater [1, 2], a variety of challenges such as sedimentation, swimming layers, pump clogging [3] or air entrainment [4] occur in pumping stations. In order to implement the most trouble-free and low-maintenance operation possible, special attention must be paid in the design phase to aspects such as the shape of the pit, the layout of the inlet, the geometry of the sloped walls, the pumps and much more. To validate these parameters, an investigation using hydraulic models is recommended [5, 6].

### 1.1. Wastewater Pumping Stations

Wastewater transport using pressure pipes can be realized by upstream wastewater pumping stations. These structures can vary greatly in size and design. In principle, they can be classified according to the pumps used. Dry-installed pumps are housed in separate machine rooms, as shown in Figure 1a). While this allows easier maintenance and inspection of the machines, it requires increased constructional investment. Wet-installed pumps are placed directly in the suction chamber, as shown in Figure 1b) [7].

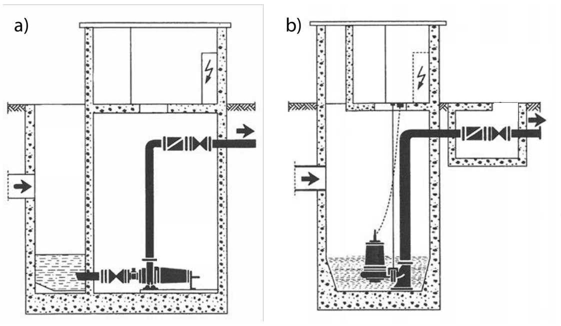


**Figure 1. Wastewater pumping station with a) dry-installed and b) wet-installed pumps [7]**

The pumping station described in this paper is a variant with dry-installed pumps. The relevant standards contain recommendations for these systems for pumps positioned next to each other. This constellation often results in a suction chamber which is rectangular in shape and provides increased opportunities for particle deposits around the edges. In order to achieve a higher flow velocity and thus better activation of particles, a circular suction chamber with dry-installed pumps was developed as the initial concept. A central cone was used to increase particle movement and prevent the formation of a swimming layer in the outer channel. A schematic top view of the pump station is shown in Figure 2a). A sectional view is shown in Figure 2b). Dashed arrows symbolize the wastewater flow in both illustrations from inlet to the pumps. The left and middle outlets represent the two rainwater pumps, and the right pipe shows the position of the dry weather pump.

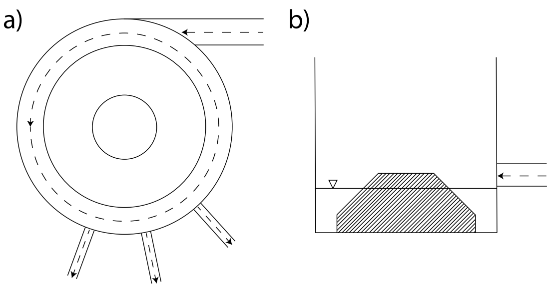


**Figure 2. Concept of a round suction chamber with central cone, a) top view, b) sectional view**

The connection to the wastewater network takes place in two stages over several years, during which the number of inhabitants covered increase. In order to cover the two operating requirements, both expansion stage 1 with a lower incoming volume flow and expansion stage 2 with an increased flow are taken into consideration in the following investigations.

## 2. METHOD

### 2.1. Dimensioning

In order to carry out a fluidic analysis using a hydraulic scaled model, a calculation according to the relevant similarity laws is of immense importance. For an application with free water surfaces, as it is the case in the suction chamber under consideration, modelling according to the Froude similarity, which shows a ratio of inertial force to gravitational forces, is suitable [8, 9].

$$Fr = \frac{v}{\sqrt{g \cdot D}} \tag{1}$$

In order to calculate the similarity, the Froude numbers of the original and the model must remain identical [8, 9].

$$\frac{Fr_M}{Fr_G} = 1 \tag{2}$$

When determining the scaling dimension, viscosity effects and surface tensions must be taken into account. By including the Reynolds number Re and Weber number We, scaling limits can be identified [6].

Inertial and viscous forces are considered using the Reynolds number Re.

$$Re = \frac{v \cdot D}{\upsilon} \tag{3}$$

The Weber number We is used to account for inertia and surface forces.

$$We = \frac{v^2 \cdot D \cdot \rho}{\sigma} \tag{4}$$

Recommendations for value limitations for the selection of these two key figures can be found in the relevant literature. According to [6, 10], the Reynolds number should be in a range of $Re > 3x10^4$ and the Weber number should be greater than $We > 120$. An additional safety factor of 2 is recommended for both values.

The geometrical similarity must likewise be maintained. In this context, all dimensions od the systems under consideration must be in a fixed ratio to reach other [8].

$$M = \frac{L_M}{L_O} = const. \quad (5)$$

Table 1 provides the conversion of various dimensioning parameters between the model and the original.

**Table 1. Froude similarity scaling rules [9]**

| Parameter | Conversion |
|---|---|
| Lengths | $L_O/L_M = M$ |
| Areas | $A_O/A_M = M^2$ |
| Velocities | $v_O/v_M = M^{1/2}$ |
| Times | $T_O/T_M = M^{1/2}$ |
| Flow rates | $Q_O/Q_M = M^{5/2}$ |
| Forces | $F_O/F_M = M^3$ |

### 2.2. Test Rig Design

After applying the design parameters presented in advance, a scaling factor of 1:3.66 was selected. In order to be able to observe comprehensive sedimentation investigations, the suction chamber was constructed out of transparent polyvinyl chloride (PVC) and methyl methacrylate (PMMA). In addition, a water supply network with a water supply tank and speed-controlled pumps were implemented to enable different volume flows and water levels in the modelled suction chamber. A particle injection and filter were installed as well. All components assembled form the test rig are shown in Figure 3.

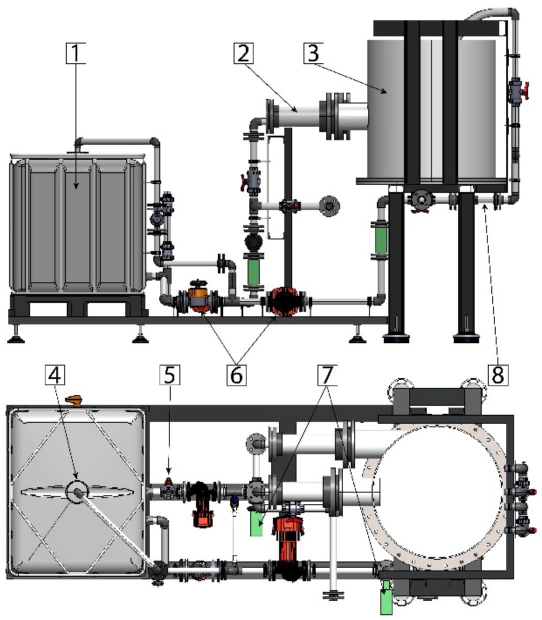


**Figure 3. Test rig**

The components shown in the graphic include 1) the water supply tank, 2) inlet pipe into the model tank, 3) the model tank, 4) particle filter, 5) particle injection chamber, 6) pumps, 7) magnetic-inductive flow meter, 8) suction pipe exciting the model tank. The inlet and outlet pipes as well as the pumps are fitted with additional connecting pipes to ensure a dispensing of air of the individual lines.

The selected resulted scale of the model tank is shown in Table 2.

**Table 2. Model suction chamber dimensions**

| Parameter | Value |
|---|---|
| Scale | 1:3.66 |
| Diameter | 0.93 [m] |
| Height | 1.46 [m] |
| Volume | 0.99 [m$^3$] |
| Number of Pumps | 3 |

### 2.3. Artificial Wastewater

The composition of particles in wastewater systems has been subject of numerous studies. Crabtree [1] created a classification of different sediments, which was expanded by Kirchheim [2]. Further investigations regarding the wastewater medium were conducted by Mitchell in [3]. Table 3 shows a selection of the particles found in sewer systems.

**Table 3. Selection of wastewater particles**

| Label | Density ρ [kg/m$^3$] | Particle size d [mm] |
|---|---|---|
| Gravel, sand, sludge | 1,000-2,150 | 0.4-15 |
| Fine sand | 1,230-2,000 | 0.5-9 |

As the sources describe very high deviations in the weight and density of the respective particles, depending for example on the time of year and the catchment area, different coloured plastic granules were selected to illustrate the different particle behaviour. Red granulate, which is shown in Figure 4a), with a density of 1,080 [kg/m$^3$] describes fine sand. Heavy black granulates, which is shown in Figure 4b), with a density of 1,470 [kg/m$^3$] represents heavy particles.

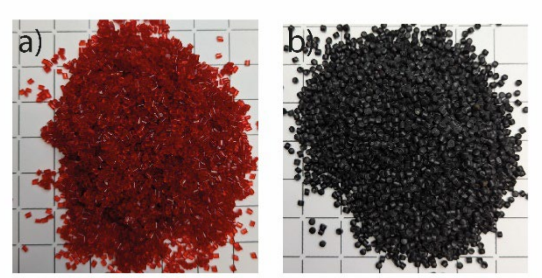


**Figure 4. Sediments used to replicate artificial wastewater a) light granulate, b) heavy granulate**

The purpose of the particles used is not to achieve an accurate representation of the wastewater, due to its high deviation of particles, but to identify zones with average high sediment accumulations. By using two different types of particles, it is easier to visualise the deposition areas of lighter and heavier sediments. Optimisation of these areas can be achieved in subsequent steps.

### 2.4. Experimental Procedure

The test sequences are based on a realistic pumping station operation. The inlet volume flows and pump volume flows are applied based on the average daily hydrograph. The average dry-weather discharge $Q_A$, the expected dry-weather peak $Q_P$ and the maximum volume flow during a rain event with mixed water inflow $Q_{MAX}$ provide the operating points under consideration. The scaled values of the inflow, respective pump flow and the corresponding activation and deactivation levels of the two expansion stages can be found in Table 4.

**Table 4. Parameters of used volume flows and water levels**

| **Expansion stage 1** | $Q_A$ | $Q_P$ | $Q_{MAX}$ |
|---|---|---|---|
| Inflow [l/s] | 0.71 | 1.24 | 2.49 |
| Outflow [l/s] | 1.99 | 1.99 | 2.40 |
| Activation level [m] | 0.22 | 0.22 | 0.30 |
| Deactivation level [m] | 0.11 | 0.11 | 0.11 |
| **Expansion stage 2** | | | |
| Inflow [l/s] | 1.24 | 3.11 | 4.56 |
| Outflow [l/s] | 3.00 | 3.00 | 4.40 |
| Activation level [m] | 0.27 | 0.36 | 0.42 |
| Deactivation level [m] | 0.11 | 0.11 | 0.11 |

At the respective operating point, a constant inlet volume flow fills the model tank. When the defined activation level is reached, the respective pump is switched on and discharges water from the tank until the water level reaches the deactivation level. Filling and draining the tank between these two levels is referred in the following as a pump iteration. When carrying out experiments, a defined quantity of red and black particles is added to the inlet flow, which are collected again with a filter unit at the end of the test rig. 420 g red particles and 267 g of black particles, which correspond to a poured volume of 600 ml and 300 ml in the respective cases, are used. The particle injection takes place in the active inlet flow during the first pump iteration. After a thorough review phase, the maximum number of pump iterations was set to 10. In almost all cases, particle movement could hardly be observed after the intervals had elapsed. If all particles are removed from the model tank before the tenth pump cycle is reached, it is regarded as a stop criterion. At the end of the test, the black and red particles are removed from the filter, separated, dried and then weighed.

In addition, to the validation of the discharged particles, remaining sediments in the model tank are documented. To ensure a precise description of the deposition formation, the base of the test setup was marked as illustrated in Figure 5.

**Figure 5. Marked model tank base**

These investigations help to understand the basic behaviour of the pump sump and to identify the isolated influence of volume flows and water levels on the particles.

## 3. RESULTS

### 3.1. Modification A

Modification A is the implementation of the concept of a suction chamber with a central cone presented in chapter 1.1., which is illustrated in Figure 6.

Figure 7 shows the sketched particle deposits after ten pump iterations during operation in expansion stage 1. As depicted in Figure 7a), both the lighter red particles and the heavier black particles sediment immediately after reaching the pump sump. The detachment of some particles and the movement along the clockwise direction, i.e. against the intended flow direction in the channel to the pumps, can be seen. During operation, the suction flow of the pump dominates and activates a part of the sedimented particles. In Figure 7b), when using a higher volume flow of $Q_P$, an activation of red particles towards the pumps can be seen. However, due to the channel flow that appears, sedimentation zones form again in the area of the cone, which cannot be broken down. Nevertheless, the flow conditions in the pump sump are not yet sufficient to activate the black particles. As expected, the best effect can be observed during a rain event with a volume flow of $Q_{MAX}$ depicted in Figure 7c). Both types of particles were almost completely removed.

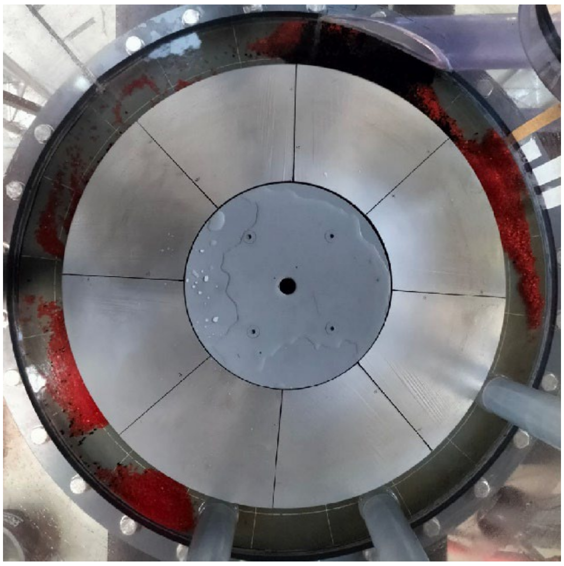

**Figure 6. Round suction chamber with a central cone**

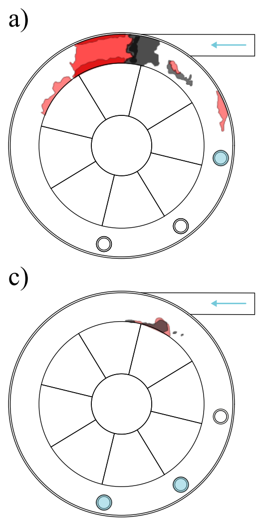


**Figure 7. Outline of the particle depositions in expansion stage 1 at a volume flow of a) $Q_A$, b) QP and c) $Q_{MAX}$**

Figure 8 shows the discharges particle quantities in percent of the respective investigations.

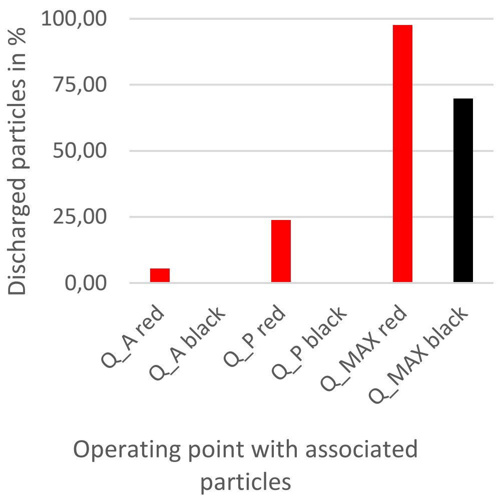


**Figure 8. Percentage of discharges particles at expansion stage 1**

For the subsequent expansion stage 2 with a higher volume flow, a significantly better movement of the particles can be observed compared to expansion stage 1. During operation at $Q_A$ in Figure 9a), activation of the light sediments can already be seen. However, the heavier black sediments still did not reactivate. Significantly higher discharge quantities of particles were achieved in operation at $Q_P$ as shown in Figure 9b). As in the previous expansion stage 1, almost all particles could be discharges from the model at the high-volume flow $Q_{MAX}$ during a rain event as illustrated in Figure 9c).

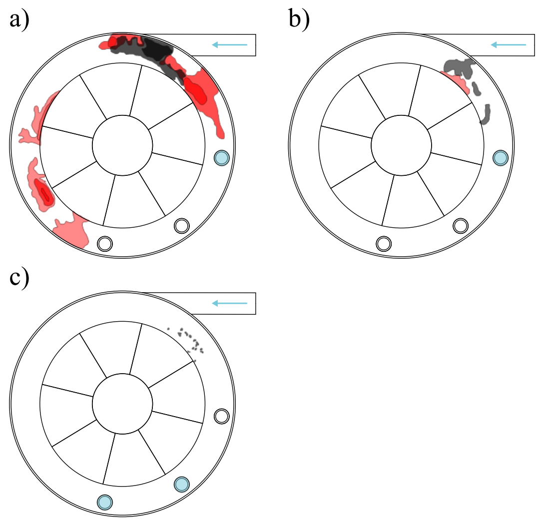


**Figure 9. Outline of the particle depositions in expansion stage 2 at a volume flow of a) $Q_A$, b) QP and c) $Q_{MAX}$**

A significantly better removal of the particles in expansion stage 2 is also underlined by the increased discharge quantities shown in Figure 10.

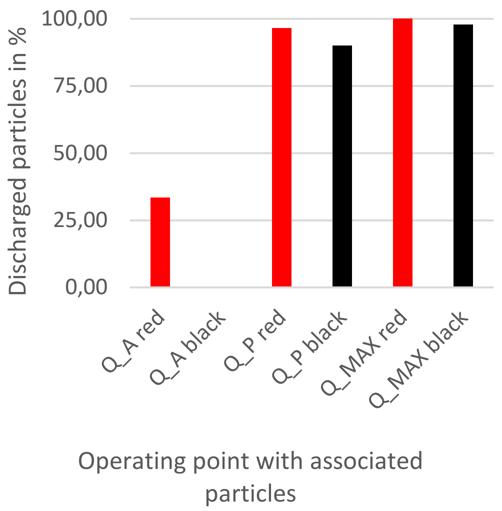


**Figure 10. Percentage of discharges particles at expansion stage 2**

In the course of further investigations, several additional concepts were developed and examined. These included, among other things:

- Test series with different pump positions
- Eccentric cone placement
- Increasing of the cone diameter

Even though some of the measures listed were able to remove higher quantities of particles, it was not possible to achieve a conversion with a complete particle removal after ten pump iterations in any of the test series. For this reason, a fundamentally different modification was implemented.

### 3.3. Modification B

Modification B follows the approach of making maximum use of the vortex created by the tangential inflow and the particle transport it supports. Figure 11 shows the particle transport for a) $Q_A$, b) $Q_P$, c) $Q_{MAX}$ without built-in sloped walls. Even without installations, a clear movement of the particles towards the center of the model tank can be observed.

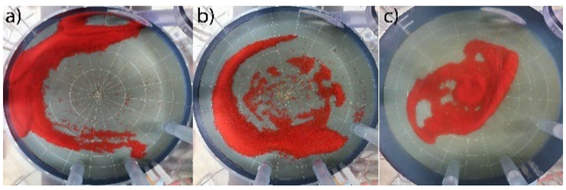


**Figure 11. Particle transport with tangential inflow at a) $Q_A$, b) $Q_P$ and c) $Q_{MAX}$**

Based on this idea, a circular suction chamber with three dry-installed pumps was developed, in which the pump positions are shifted by 45°. Movable pipes make it possible to vary the positions of the individual suction intakes and to investigate different considerations, such as a central suction intake or three intakes at an identical distance from the center. A design layout with a) top view and b) sectional view is given in Figure 12.

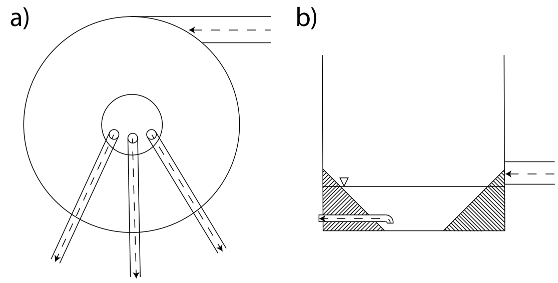


**Figure 12. Design of Modification B, a) top view, b) sectional view**

The investigations with the new pump sump design started with the test series of expansion stage 1 with the lowest volume flow $Q_A$. All particles were discharges from the suction chamber after just the third pump iteration. Figure 13 shows a view from below of the model tank after a) one, b) two and c) three pump iterations.

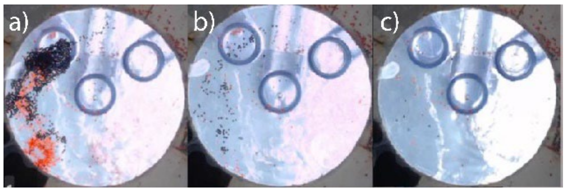


**Figure 13. View from below into the model tank at a volume flow $Q_A$ and a) one, b) two, c) three pump iterations**

The high discharge performance was maintained across all test scenarios at operating point $Q_A$, $Q_P$ and $Q_{MAX}$ for both expansion stage 1 and expansion stage 2.

### 3.4. Comparison of Results

Modification A showed good results in removing the particles at higher volume flows $Q_{MAX}$ and partially $Q_A$. However, with the exception of rain events, it was never possible to completely remove all particles within ten pump iterations. Even further optimizations of modification A could only show partial improvements.

The use of modifications B resulted in a significant increase in particle removal. Even at expansion stage 1 with volume flow $Q_A$, it was possible to achieve early test termination due to complete particle discharge.

In further investigations, an adjustment of the activation and deactivation level as well as a flow simulation of the pump sump should be aimed for.

## 4. CONCLUSION

It was shown that hydraulically scaled model investigations are a very efficient tool for the validation and optimization of a wastewater pumping station with regard to sedimentation. Numerous parameters can be varied and evaluated for their influence.

## REFERENCES

[1] Crabtree, R. W.. *A Classification of combined sewer sediment types and characteristics*, 1988

[2] Kirchheim, Norma. *Kanalablagerungen in der Mischkanalisation*, 2005

[3] Mitchell, R. L., 2019, "Causes, Effects and Solutions of Operational Problems in Wastewater Systems Due to Nonwoven Wet Wipes", *Dissertation Technische Universität Berlin, Fakultät V Verkehrs- und Maschiensysteme*

[4] Ackl, R. A., 2018, "Enhancing the Design of the Wet Pit Pumping Stations Based on Experimental and Numerical Investigations", *Dissertation Technische Universität Berlin, Fakultät V Verkehrs- und Maschiensysteme*

[5] DWA-Regulation, DWA-A 120 - 2 *Pumpsysteme ausserhalb von Gebäuden – Teil 2 Pumpstationen und Drucksysteme,* 2022

[6] ANSI/HI 9.8-2018, 2013, "American National Standard for Rotodynamic Pumps for Pump Intake Design"

[7] Surek, D., 2014, *Pumpen für Abwasser- und Kläranlagen*, Springer Fachmedien Wiesbaden

[8] Surek, D., Stempin, S., 2017, *Technische Strömungsmechanik*, Springer Fachmedien Wiesbaden

[9] Strobl, T., Zunic, F., 2006, *Wasserbau*, Springer Berlin Heidelberg

[10] Heller, V., 2011, "Scale Effects in physical hydraulic engineering models", *Journal of Hydraulic Research,* Vol. 49, No. 3, pp. 293-306