Potentials of adaptive inlet systems for secondary clarifiers - illustrated using the example of the Dresden wastewater treatment plant

Summary

Secondary clarifiers often limit the efficiency of the wastewater treatment plant. If capacity expansions or lower discharge of suspended solids are necessary, it is worthwhile to determine the performance-enhancing potential of height-variable inlet system by means of flow simulations (CFD) before installing additional tanks and filter systems. The installation of height-variable inlet Passavant® hydrograv® adapt systems were a goal oriented measure for the secondary clarifiers of the Dresden wastewater treatment plant.

After the rebuild, the clearly positive effects predicted by CFD are confirmed not only on turbidity, suspended solids and phosphorus values in the effluent, but also in the increased loading capacity of the secondary clarification. Thus the constructional extension was avoided and at the same time the discharge values were significantly improved. For wastewater treatment plants without filtration, height-variable inlet systems thus define the state of the art of particle-related discharge values that can be achieved - with average turbidity values around 2 FNU in dry weather at a comparable level with many filter systems; and this with simultaneous capacity growth.

Environmental interface

Secondary clarifiers regularly represent the interface to the environment for wastewater treatment plants and therefore have a particularly high influence on the efficiency of the entire wastewater treatment plant. The interdependency of the fluctuating load and the load-dependent variable optimum geometry of the inlet structure of the secondary clarifiers dominate both the retention of suspended solids and the material and hydraulic loading capacity of the activated phase that can be achieved. Due to the wide range of loads regularly encountered in wastewater treatment plants, resulting in extremely different sludge levels, hydrograv developed height-variable inlet systems for secondary clarifiers that automatically optimize to the current load. With these systems, the position and opening width of the tank inlet are continuously optimized with regard to the current loads (Q, MLSS, SVI) and thus the sludge level.

The efficiency of secondary clarifiers is dominated by fluid mechanical processes and the associated geometry and is essentially determined by the following influences:

- The concentration of sludge induces density effects that dominate flow physics.
- The settling behaviour of the sludge, which is described by the sludge volume index.
- The thickened sludge is drawn off with a high volume flow, which means an increased inflow for the secondary clarifier.

Conventional tank inlets were previously rigid and therefore always discharge the sludge-water mixture at a fixed height. However, the bigger the distance between the sludge level and the inlet height, the more disturbing the density effects. If the inlet is above the sludge level, the inflow stream passes through the clear water and the inflowing sludge whirls flakes into the clear water. Since activated sludge hardly settles as a single flake, sludge introduced into the clear water via the density waterfall is discharged via the clear water outlet and leads to increased particle-bound effluent values of the wastewater treatment plant.

If, on the other hand, the discharge takes place below the sludge level, individual bacteria remain trapped in the sludge and do not cloud the clear water. This phenomenon is called "flake filter effect". However, with increasing sludge bed height and thus increasing distance of the sludge level above the inlet height, more and more sludge is whirled up again and thus the efficiency of the tank is strongly impaired. The internal volumetric flow rates increase massively and the tank is subjected to significantly higher loads than the rated load of qA, MLSS and SVI would suggest (Armbruster, 2004). In addition, a deep inlet structure lowers the suspended solids in the activated sludge by unnecessarily strong sludge displacement in the case of mixed water inflow and thus reduces the capacity for nitrogen decomposition. In addition, the sludge level rises and the hydraulic capacity and operational safety against sludge drift is reduced.

Initial condition of the Dresden secondary clarifiers and analysis of operating data

The activated sludge stage of the Dresden wastewater treatment plant is currently being expanded. Flow simulations were to be used to analyze the extent to which the suspended solids in the activated sludge can be increased by rigid or height-variable modification of the inlet structures of the secondary clarification while at the same time securing the cleaning targets of the plant.

The secondary clarification of the Dresden-Kaditz wastewater treatment plant consists of six circular tanks with a diameter of 48.5 m and a 2/3 depth of approx. 4.62 m (Fig. 1). The central structure has a diameter of D = 6.0 m. The inlet opening arranged 2.56 m above the sole has an opening width of approx. 1.15 m and vertical lamellas. The tanks are equipped with shield scrapers, the clear water is drained via submerged pipes.

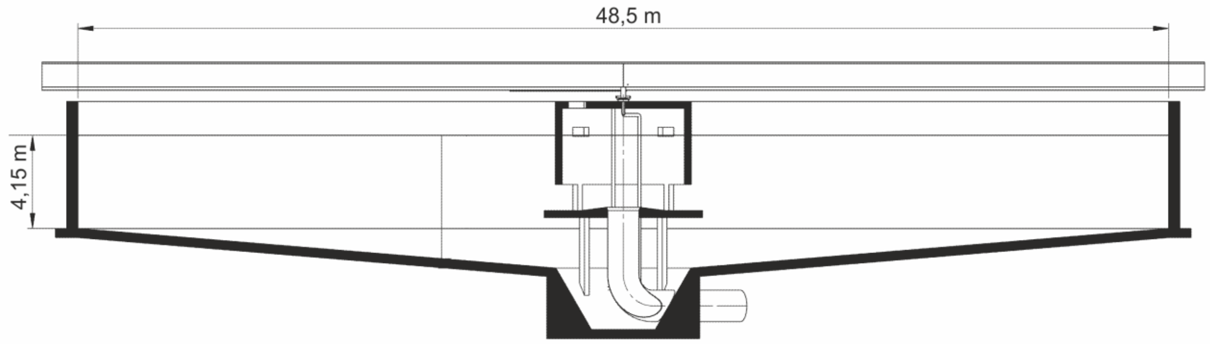

Figure 1: Secondary clarifier of the Dresden-Kaditz wastewater treatment plant. Cross section.

The task of a proper CFD investigation is not only to optimize and verify the tanks for an ideal design load, but also for their entire actual loading range in dry and rainy weather and in low and high suspended solids and SVI. The task of a wastewater treatment plant is not only to achieve the best achievable effluent values temporarily for a more or less randomly selected loading combination, but also to secure them at all times for any realistic loading. For this reason, hydrograv performs a comprehensive statistical analysis of the operating data prior to the flow simulations in order to record the loading range as well as possible. From this, three and more relevant loading cases for low, medium and high loadings are derived, on the basis of which the tanks are evaluated both in their initial state and the optimization possibilities are worked out. For the most common loading combination "medium load" (50 %-percentile of the sludge volume) an optimized inlet structure is derived. For the low loading case (10 % percentile of the sludge volume), the functional safety against flake discharge with increased suspended solids must be demonstrated. At high load (95 % percentile of the actual sludge volume occurring at the wastewater treatment plant) the functional safety against sludge discharge is proven. For the Dresden-Kaditz wastewater treatment plant, the two-dimensional analysis of the frequency distribution of the reference sludge volume (see Fig. 2) led to the loading cases listed in Table 1.

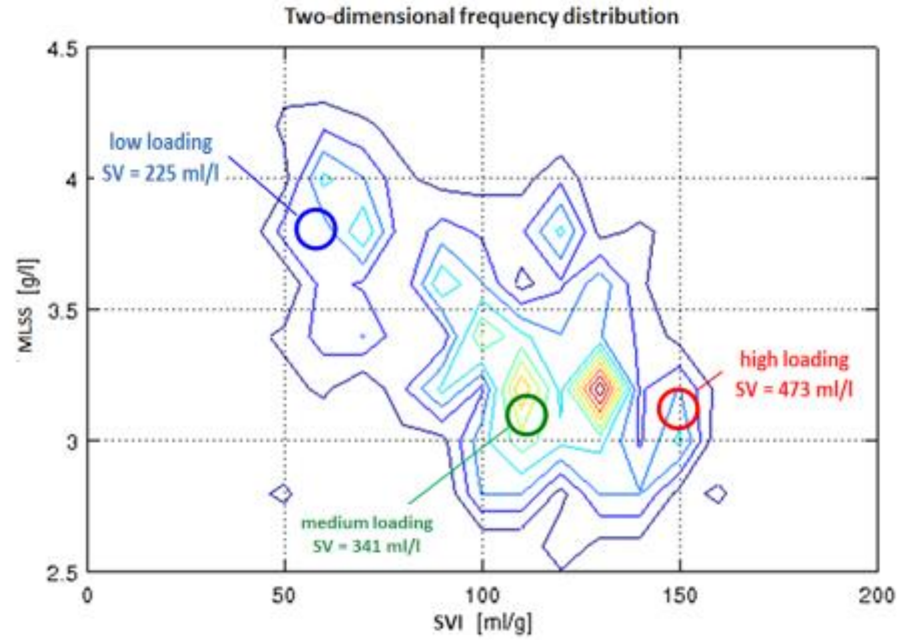

Figure 2: Operating data evaluation with two-dimensional frequency distribution of the SVI and the MLSS. Largest frequencies in the brown-red range.

Table 1: Loads in the simulations for basic optimization (SV mean load) and for functional verification (SV high and SV low load).

Parameter	**SV - low load**	**SV - medium load**	**SV - high load**
Inflow WWTP dry weather [l/s]	720	1.213	2.041
Inflow WWTP rain weather [l/s]	4.000	4.000	4.000
MLSS [g/l]	3,76	3,10	3,25
SVI [ml/g]	60	110	150
$(q_{SV})_{\text{rain weather}}$ $[l/(m^2 \cdot h)]$	297	450	643

Optimization possibilities and modification demonstrated by CFD-simulation

In the original central structure, the rigid inlet opening is far above the sludge level even at medium loads - the density waterfall is clearly visible in Figure 3 - this leads to high turbidity in the clear water zone and thus to increased effluent values due to flake discharge.

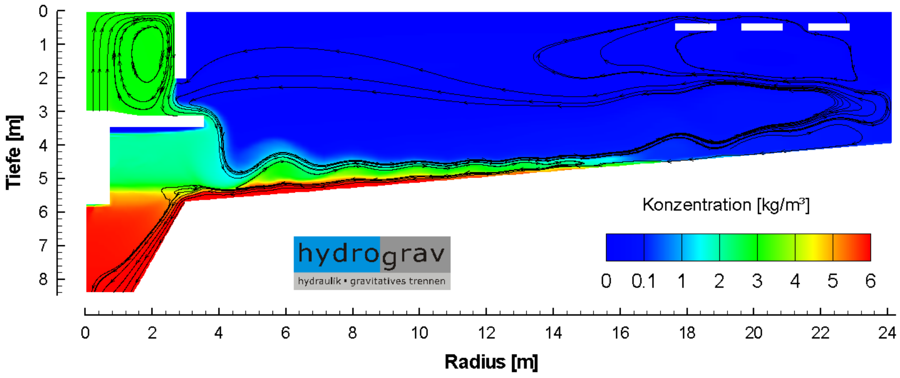

Figure 3: Simulation of existing geometry. Dry weather, mean sludge volume, concentration contour and flow paths.

Even in rainy weather (Fig. 4) the inlet opening is too high at medium loading which leads to a very unstable sludge level and a pronounced ineffective zone (suspended solids < 3 g/l, volume approx. 39 %) - and thus high turbidity and high suspended solids.

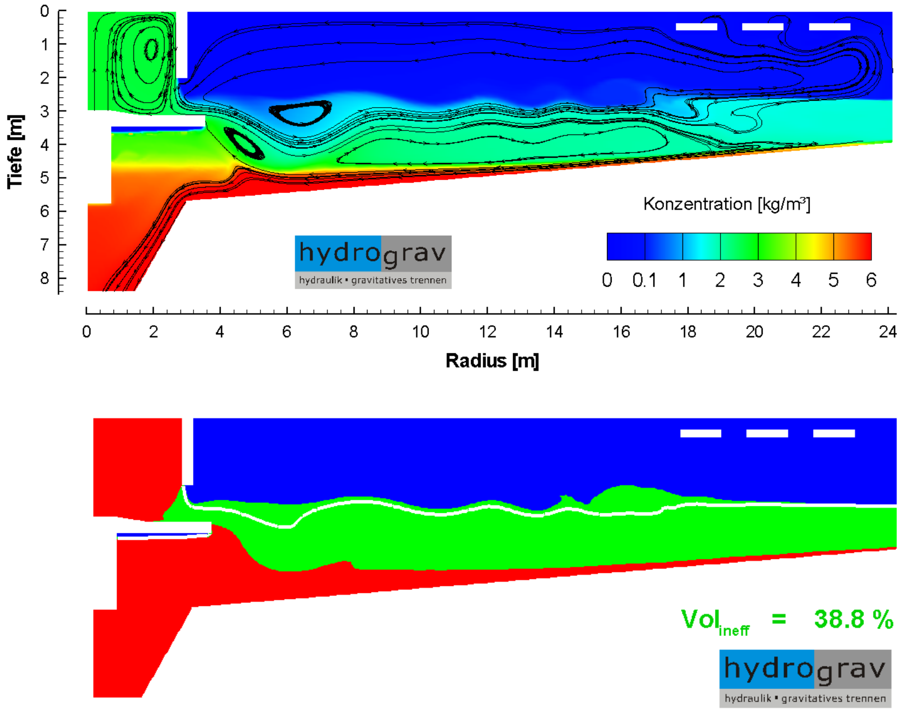

Figure 4: Simulation of existing geometry. Rainy weather, average sludge volume, top: Concentration contour and flow paths, below: Division of the concentration field into functional zones: green = ineffective zone (suspended solids < MLSS), red = area with thickened sludge, blue = clear water.

For the medium loading case, the design of an optimized inlet system is derived in the simulation study by automatic fundamental optimization. In this case, the inlet opening is located lower than the existing geometry and has a smaller opening width. The simulation result (cf. Fig. 5) clearly shows that the remaining ineffective zone (green area) with diluted sludge is very narrow and that at the same time a calm sludge level is achieved.

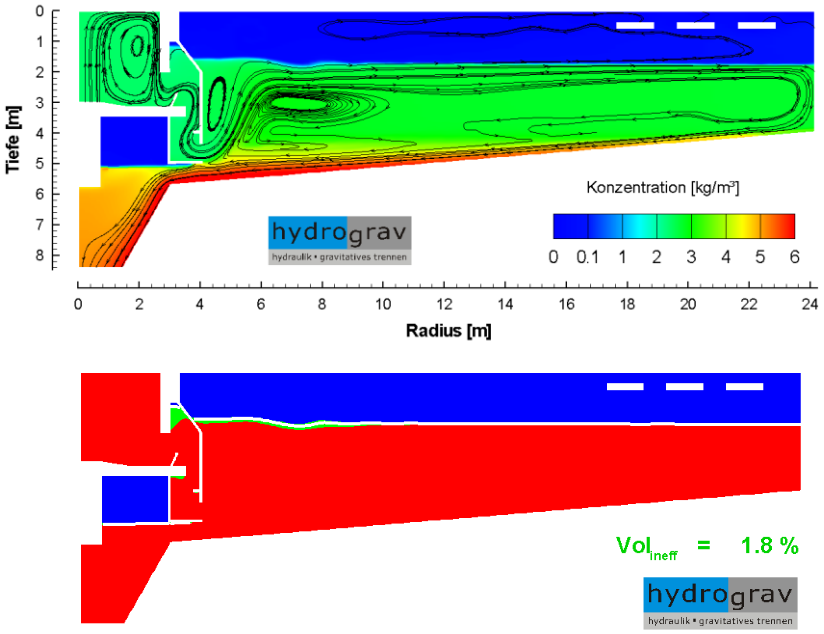

Figure 5: Simulation of optimized rigid geometry. Rainy weather, average sludge volume, top: Concentration contour and flow paths, below: division of the concentration field into functional zones: green = ineffective zone, sludge concentration smaller than inlet concentration, red = area with thickened sludge, blue = clear water.

The function of the optimized rigid inlet structure and height-variable inlet system will now be checked in the next simulation step for the SV low loading and SV high loading cases. This shows that further improvements in effluent quality can be achieved with a height-variable inlet structure, as it can be arranged significantly lower for dry weather (Fig. 6).

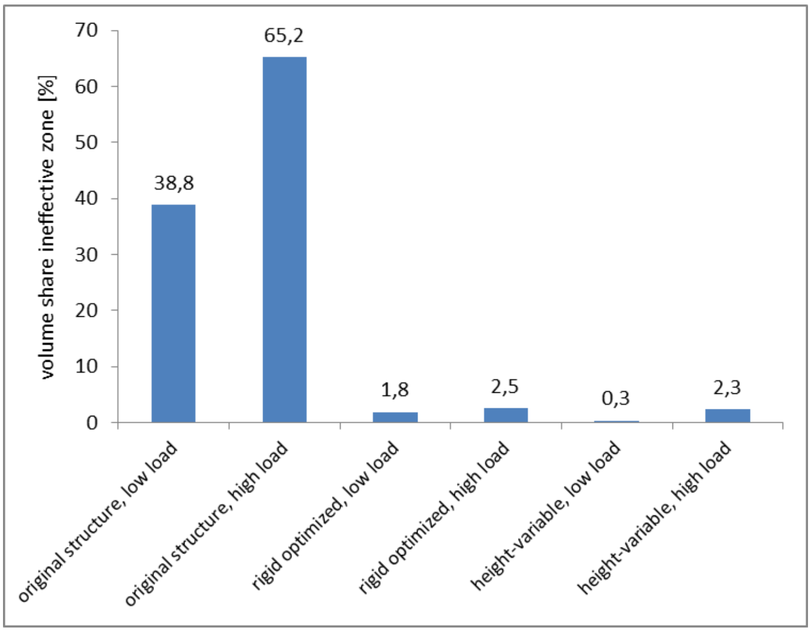

Figure 6: Size of the ineffective zone, comparison between existing geometry, rigid optimization and height-variable inlet system.

In order to check the safety against sludge discharge, the clear water heights at high loads are determined and compared. It has been shown that the high loading case with MLSS = 3.25 g/l and SVI= 150 ml/g can no longer be safely treated with the rigid inlet structure designed for low suspended solids, which now swirls up more sludge. The sludge level rises dangerously, the clear water zone is too small. Only if the MLSS were to be reduced to 3.0 g/l, which would be counterproductive for the cleaning target, would the tank still function sufficiently safe with the newly developed rigid modification. The height-variable inlet structure, which even has a higher distance to the base than the existing structure to secure the capacity at high loading, ensures a flow-mechanically optimal geometry even at 3.25 g/l and, unlike the rigid solution, there is still a clear safety reserve of almost two metres for the tank in this high loading case (cf. Figs. 7 and 8).

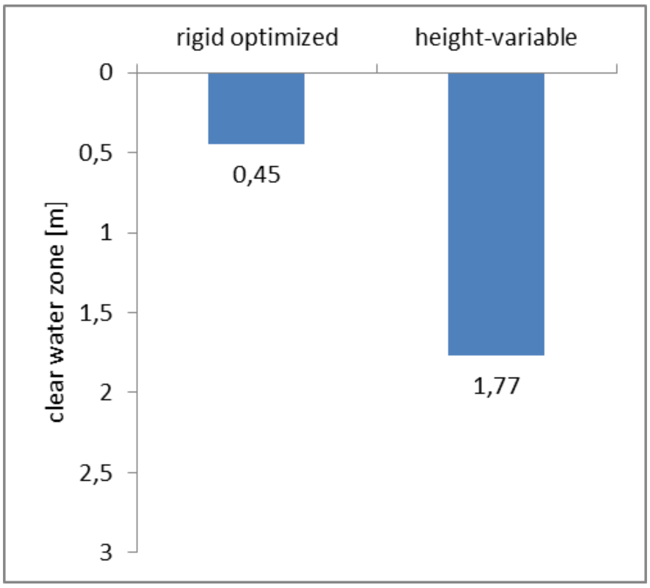

Figure 7: Height of the existing clear water zone, comparison of the optimization variants for rain weather and high sludge volume.

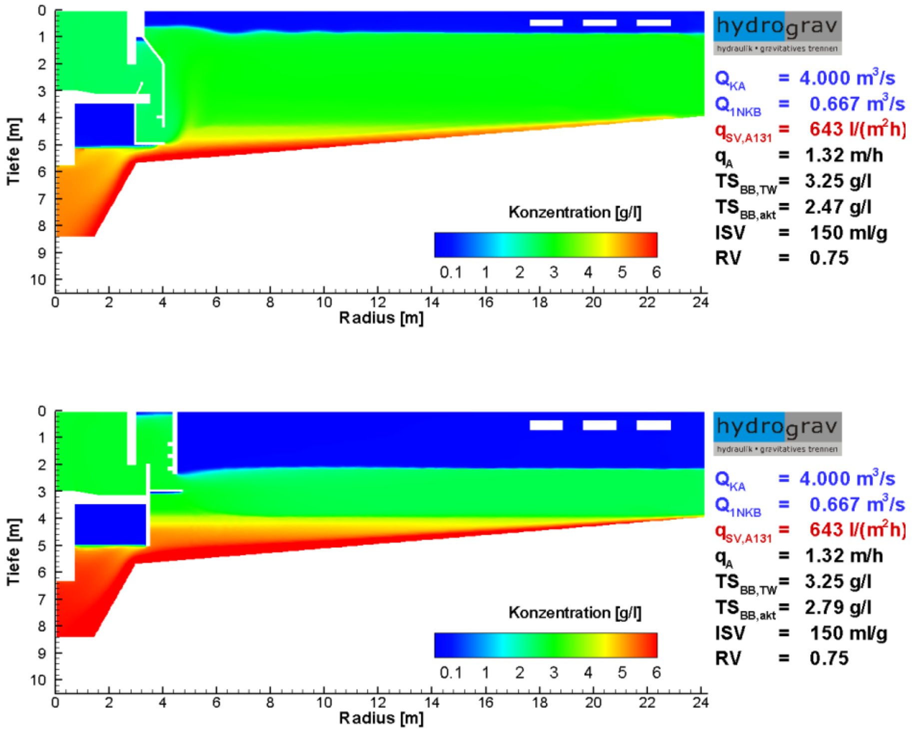

Figure 8: Simulation of rain weather, SV high loading. Concentration field. Above: rigidly optimized inlet, below: variable height inlet.

The results show that the secondary clarifier tanks with the height variable design of the inlet system are expected to have a higher loading capacity as well as a minimization of the effluent suspended solids. Because much more precisely than an improved rigid inlet structure, which is only a compromise, a height-variable inlet system continuously adjusts the flow conditions in the tank to the current optimum. The altitudes can thus be set in both directions, that is, lower and higher than any rigid compromise.

For this reason, the operator of the wastewater treatment plant decided to install height-variable inlet systems. Figure 9 shows the tanks before and during the modification. Figure 10 shows a finished inlet system (D = 9.8 m, H = 8.7 m) in high and low position. The height of the inlet opening can be adjusted by 2.9 metres, which is determined to be necessary by the flow mechanics. For practical reasons, the tanks could only be taken out of operation in autumn and winter and only one after the other. The total modification time therefore took a total of 14 months with a pure construction time of three weeks per tank.

Figure 9: Secondary clarifier of the Dresden-Kaditz wastewater treatment plant. Left: existing, right: during modification.

Figure 10: Height-variable inlet Passavant® hydrograv® adapt System in a secondary clarifier of the Dresden-Kaditz wastewater treatment plant. Left: in low position, right: in upper position.

Operating results before and after modification

The operating results show that the height-variable inlet systems achieve significantly better values for turbidity and suspended solids and thus also for COD and phosphorus. Due to the possible increase in MLSS and the reduced sludge displacement in mixed water, the modification is also expected to have a positive effect on the nitrogen discharge concentration.

Figure 11 shows the effects of the modification of the inlet structures on the effluent turbidity of the wastewater treatment plant. After the modification, the average monthly turbidity decreases to around 2 FNU continuously and is thus only one third of the values before the use of the height-variable inlet systems. During the modification, the clear water discharge was photographed simultaneously in a tank with a rigid inlet structure and the neighboring tank, which was already equipped with a height variable system (Fig. 12). The effect can be clearly seen in the fact that the purified clear water of the height-variable tank is much clearer under the same load and contains fewer individual flakes.

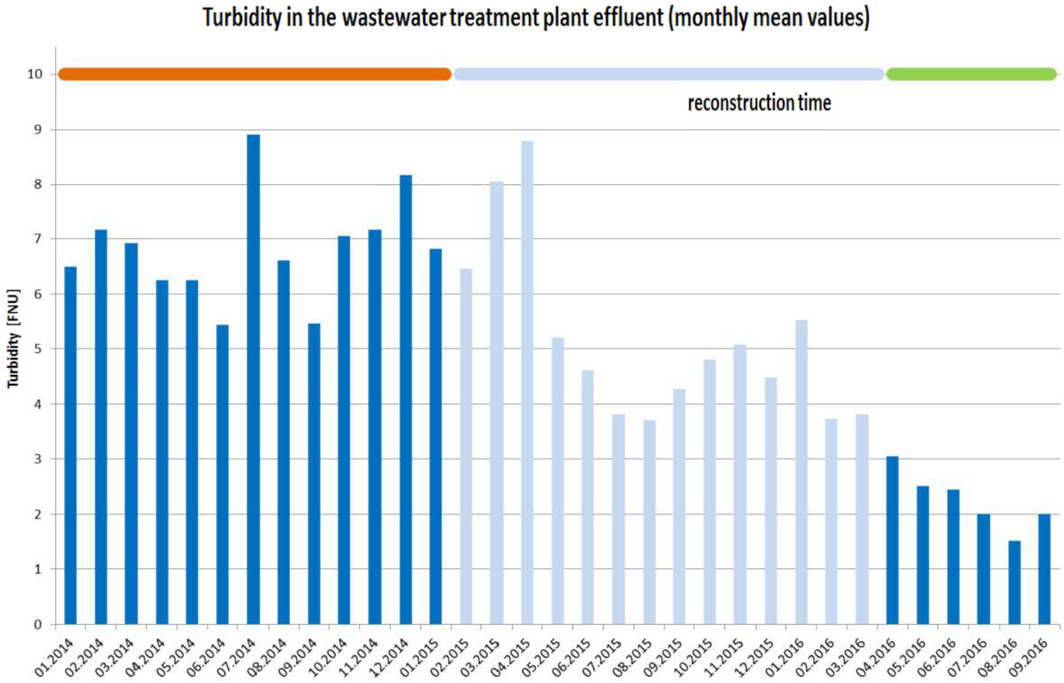

Figure 11: Turbidity in the discharge of the Dresden-Kaditz wastewater treatment plant (monthly mean values).

Figure 12: Photos from May 2015 of the secondary clarifiers in the area of the drain pipes in a tank with a rigid inlet structure (left) and an already modified tank (right).

With the turbidity also the measured values for suspended solids and the total phosphorus decreased: For P_{total}, a clear improvement of 0.1 to 0.2 mg/l was demonstrated continuously (cf. Fig. 13), although the sludge properties are worse than in previous years (cf. Fig. 14). Since 2-point precipitation before and after retrofitting operates with the same dosing strategy, the decrease in P_{total} is due to the reduced suspended solids output. After the retrofitting, with clearly reduced P_{total} in the effluent of the wastewater treatment plant, even significantly less precipitant is required.

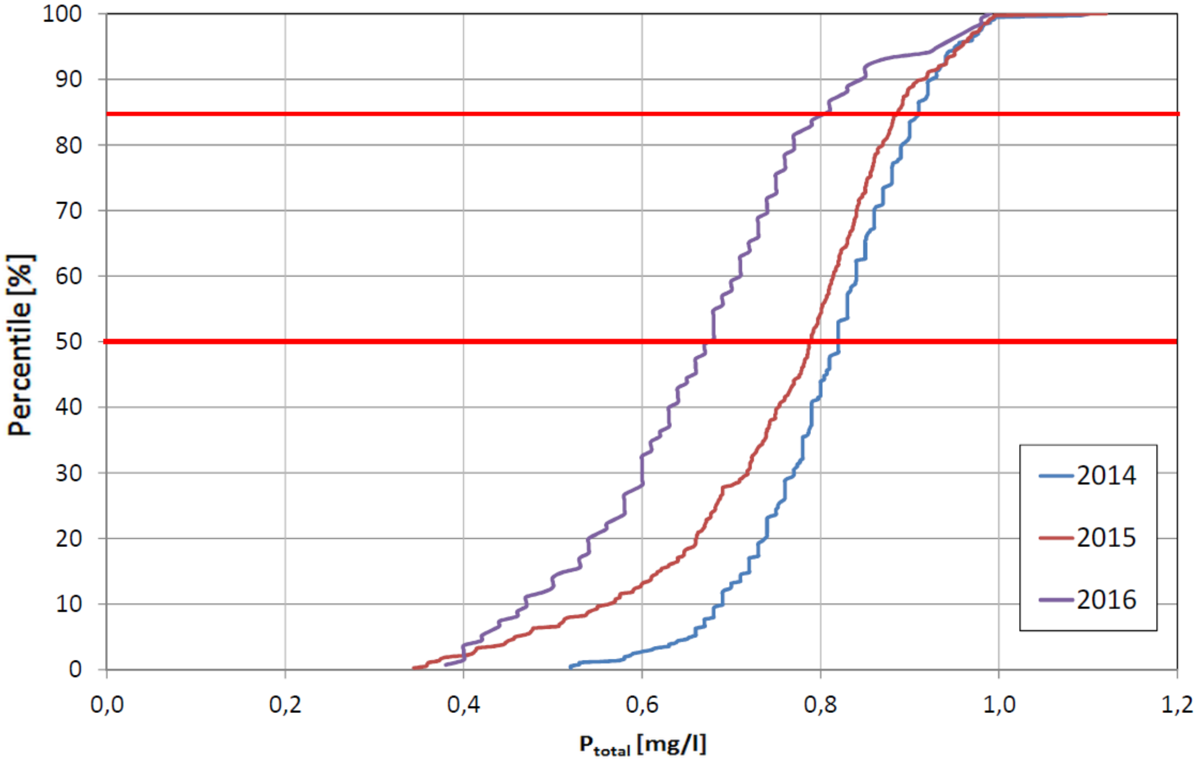

Figure 13: Cumulative frequency of the P_{total}-concentration in the effluent of the Dresden-Kaditz wastewater treatment plant. Comparison of several operating years.

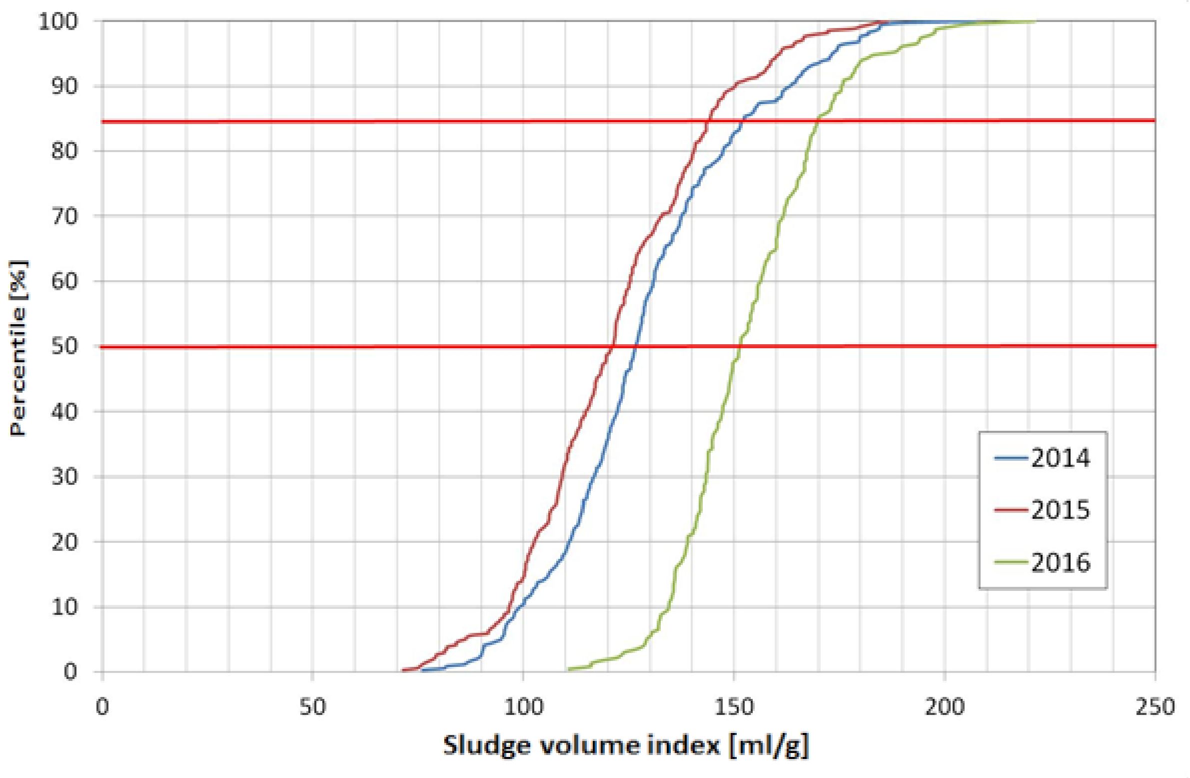

Figure 14: Cumulative frequency of the sludge volume index in the biological stage of the Dresden-Kaditz wastewater treatment plant. Comparison of several operating years.

Due to the lower sludge level at a high SVI (Fig. 14), the tanks have an increased treatment capacity and the construction of further secondary clarifiers could be avoided.

Conclusion

First of all, it can be stated that flow simulations are very well suited for developing optimization measures for water management tanks. The height-variable modification of the inlet structures of the Dresden-Kaditz wastewater treatment plant, which was then designed in detail on the basis of several hundred further simulations, is proving to be extremely useful today from both an economic and an ecological point of view on the basis of the operating result. With this relatively simple modification measure, the effluent values of the wastewater treatment plant were significantly improved even without filtration. For wastewater treatment plants without filtration, height-variable inlet systems obviously define the state of the art with minimized suspended solids and turbidity around 2 FNU. The tanks are at the same time more efficient in terms of hydraulic and material loading. With the modification to height-variable inlet systems, the structural extension of the secondary clarification for the Dresden-Kaditz wastewater treatment plant could be avoided and, at the same time, a higher amount of suspended solids for the aeration tank was made possible. For the operator, this contributed significantly to investment cost savings in the aeration tank volume. In addition, precipitants are now continuously saved in operation and this with significantly improved phosphorus effluent values at the same time.

References

Armbruster M. (2004). Investigation of the possible performance increase of secondary clarifiers with the help of numerical simulations. Dissertation, University of Karlsruhe.

Addendum

Due to program-related unfeasibility of the creation of some figures with English terms we provide a table with the English translation of all German terms found in the above article.

German	**English**
ISV	SVI
Konzentration	Concentration
Q_{1NKB}	Inflow ratio for a single second clarifier
Q_{KA}	Inflow of the whole WWTP
RV	RAS
Tiefe	Depth
$TS_{BB, ak}$	MLSS currently in the aeration tanks
$TS_{BB, TW}$	Nominal MLSS value in the aeration tanks for dry weather case

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