# Lamella Settler for Storm Water Treatment - Performance and Design Recommendations

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## Traitement des eaux pluviales avec décanteur lamellaire - Performances et recommandations pour le dimensionnement

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## RÉSUMÉ

Trois décanteurs lamellaires, deux d'entre eux dans des déversoirs d'orage sur un réseau unitaire, un à la sortie d'un système séparatif, ont été suivis sur une période de quatre ans. Le principal objectif était de déterminer l'efficacité d'abattement des matières en suspension (MES) et des polluants associés. A cette fin, des échantillonneurs de grande taille permettant de collecter d'importantes quantités de MES ont été utilisés pour pouvoir réaliser des analyses détaillées des matières solides. D'après les matières en suspension totales, le rendement moyen des installations varie entre 49 à 68%. Des valeurs similaires peuvent être atteintes pour le phosphore et les métaux lourds, ce qui est principalement dû à une accumulation de particules fines dans la charge entrante dans la station d'épuration. Sur la base d'un événement, une relation a pu être clairement établie entre l'efficacité d'abattement des MES et les deux paramètres que sont la charge hydraulique superficielle et la concentration de la charge entrante. L'ensemble des résultats de cette étude conduit à recommander pour le dimensionnement une charge hydraulique superficielle maximum de 4 m/h. Selon les résultats de cette étude, un taux d'abattement des MES supérieur à 50%, qui est défini comme minimum d'efficacité à long terme, peut être obtenu sans difficulté pour cette valeur. En plus de la limitation de la charge hydraulique superficielle maximale, la dissipation de l'énergie de la charge entrante ainsi qu'une diminution constante de la quantité d'eau claire passant au-dessus de la lamelle est inévitable.

## ABSTRACT

Three lamella settlers, two situated at the overflow of a combined sewer system and one at the outlet of a separate sewer system, were monitored over a period of four years. The main objective was to determine removal efficiencies for total suspended solids and associated pollutants. For this purpose a new sampling method based on large volume solid samplers was developed allowing a detailed analysis of solids. In regard to total suspended solids the average removal efficiency of the plants range from 49 up to 68 %. Similar values could be achieved for phosphorus and heavy metals mainly because of the high portion of fine particles in treatment plants influent. A clear dependency between solid removal efficiency and the parameters maximum surface load and influent concentration could be observed on single event basis. The aggregation of all findings of this study result in a recommended maximum design surface loading rate (SLR) of 4 m/h. According to the results of this study a solid removal rate of 50 % which is defined as minimum long-term efficiency can be achieved safely at this SLR. In addition to the definition of the maximum SLR a proper dissipation of the inflow energy and an equal collection and discharge of the clear water above the lamella turn out to be essential.

## KEYWORDS

Design, Efficiency, Lamella settler, Solids, Surface loading

# 1 INTRODUCTION

According to recent mass balances in river systems (Fuchs et al., 2010a), diffuse urban emissions (combined sewer overflows CSO und storm sewer outlets SSO) are one of the most important contributors to the overall pollution of German river systems. About 37 % of the total zinc load and 21 % of the total PAH load in river Rhine are realized via CSO and SSO while both pathways are representing in only 2 % of the river Rhine average discharge. These data emphasize the predominant role of sewer systems for the emissions of a number of anthropogenic pollutants. High loads of suspended solids which are emitted into surface waters by combined sewer overflows and storm water outlets in particular are responsible for these results. Thus, the implementation of efficient methods of storm water treatment aiming at suspended solid control is a general need in combined and separate sewers. The process technology most common implemented is sedimentation. Recent studies (Fuchs et al., 2010b) show that the efficiency of sedimentation tanks is weak if it is considered that the removal of fine particles and pollutants adsorbed to them is the primary aim of storm water treatment. For standard settling tanks dimensioned on the basis of a maximum surface load of 10 m/h the reported suspended solid removal rate ranges between 0 and 30 %. This results mainly from remobilization processes occurring during single events at which the maximum surface load is reached.

Lamella settler could help to overcome the shortcomings of standard settling tanks by increasing the given surface area significantly. They frequently are being used for chemical and industrial waste water treatment as a very efficient technology for solid separation.

Since the 1970s numerous investigations have been carried out on the application of plate and tube settler in the field of municipal waste water treatment (Burkhalter, 1978; Dorgeloh et al. 1996; Plass, 1998; Buer, 2000). The published studies describe the beneficial effects of lamellas, e. g. in respect to the inflow conditions in secondary clarifiers or the increase of treatment capacity of biological reactors respectively. Nevertheless the technology has not been applied widely because of practical constrains like sludge accumulation in tubes or difficulties in dimensioning.

The findings of the studies mentioned above are not entirely transferable to storm water treatment. Most obviously because of the fundamental differences in the dynamics of solid concentrations and discharges during storm events. In the context of storm water treatment only a few studies have been conducted (Krauth & Bondereva, 2000; Dohmann et al., 2003; Boogard et al., 2010) and even if the authors affirm the beneficial effects of lamella settlers, the application of this technology is still very limited.

Based on the aforementioned background, a four year investigation on the effectiveness and constraints of lamella settlers considering three storm water treatment plants was carried out.

# 2 METHODOLOGY

## 2.1 Treatment Plants and Investigation Sites

Investigations on the efficiency of lamella settler enclose three storm water treatment plants. Two of them were initially operated as conventional overflow tanks in a combined sewer system and later on upgraded with tube settlers. The one remaining was newly designed and constructed in a separate sewer system and equipped with lamella settlers from the beginning. The most important characteristics of the three plants are summarized in table 1.

Table 1: Characteristic numbers of the storm water treatment plant considered

| | CSS 1 | CSS 2 | SSS 1 |
|---|---|---|---|
| Impervious Area $A_{imp}$ in ha | 118 | 41.5 | 74.3 |
| Volume $V_{tot}$ in m³ | 980 | 547 | 130 |
| Spec. Volume $V_{spec}$ in m³/ha | 8.3 | 16.1 | 3.18 |
| Effective Surface Area $A_{eff}$ in m² | 1639 | 1150 | 300 |
| Design Flow $Q_{treat}$ in l/s | 1448 | 1220 | 500 |
| Maximum Surface Loading Rate $SLR_{max}$ in m/h | 2.9 | 3.8 | 6.0 |
| Flow to WWTP $Q_d$ in l/s | 140 | 35 | -- |

The plants considered in this study are covering a wide range of catchment properties. The first plant "Combined Sewer System 1" (CSS 1) is located at the end of a large and flat catchment in the Upper

Rhine Valley. The plant "Combined Sewer System 2" (CSS 2) represents a smaller, rural catchment in the hilly region of the Northern Black Forest. The last plant "Separate Sewer System 1" (SSS 1) takes the storm water from a further rural catchment which is also located in the Northern Black Forest and represents a mid-position in regard to the catchment size. It is noteworthy that the specific volume of the settling chamber of this plant is very small because lamella settler was included in the design.

All treatment plants were emptied and cleaned on single event basis during the investigations but in the case of SSS 1 parasite water filled the volume of the settling chamber during dry weather conditions so that the storm water storage capacity of the plant can be neglected.

## 2.2 Field Methods

A primary aim of this study was to quantify the solid removal efficiency of the three lamella settlers taking into account different hydraulic conditions. Hence all plants were equipped either with flow or water level meters. Some measurements were realized redundant to reduce uncertainties. All raw data were recorded continuously and synchronized for further analyses.

Figure 2 shows the elements of lamella settlers, the general positioning of pumps to take water samples as well as the positions of the installed flow and water level meters. The sketch shows the configuration for the combined systems but it is transferable to SSS 1.

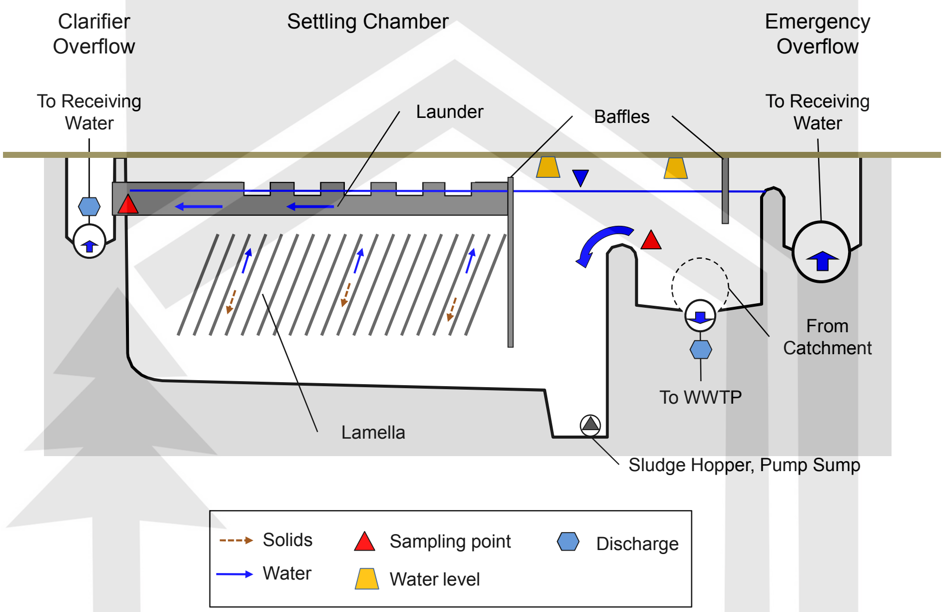


Figure 2: Principle elements of lamella settlers in combined sewer systems

Water samples were taken in two different ways. At the beginning of the investigation automatic samplers have been used to determine the dynamics of in- and outflow concentrations. However, the use of automatic samplers shows among others two serious limitations. They usually provide 24 bottles with a volume of one liter and even if all bottles are pooled the resulting volume is much too small for detailed suspended solid analyses. A further drawback of this sampling method is that according to the number of bottles and aspired temporal resolution (usually 5 minutes) the sampling time is strictly limited. Both the small sample volume and the fact that a relevant part of an event might not be monitored result in an uncertain mass balance.

Therefore, a new sampling method was applied in order to overcome the above mentioned limitations. "Solid Samplers" were installed at the influent and the clarifier overflow of CSS 2 and SSS 1. They consist of a large volume tank (1000 liters) which was filled proportional to the storm water runoff. Pumps at inlet and outlet position took a subsample every time a predefined volume has passed the in- and outflow control. In this way the hydrograph of an event could be represented and some hundreds grams of suspended solid were collected in the tanks. After a sedimentation time of at least 24 hours the supernatant was decanted and the sediments were taken for further laboratory analyses. A supernatant sample of four liter was retained to control the completeness of the sedimentation in the solid samplers.

## 2.3 Laboratory Methods

Sediment and supernatant samples were analyzed following the scheme shown in figure 3. The sediment from the soil sampler was first separated in three grain size fractions by wet sieving (clay and silt, < 63 µm; sand, 63 to 2000 µm and gravel > 2000 µm). Subsequently the dry mass (DM) was determined for all fractions and each fraction was divided in two sub-samples. One part was used to determine the organic content and the other to analyze the particle bound phosphorous and heavy metal concentrations.

The total suspended solids (TSS) and the volatile suspended solids (VSS) in the supernatant were determined after filtration through 0.45 µm membrane filters. An aliquot of the homogenized sample was used to analyze the total concentration of phosphorous and heavy metals.

All analyses were conducted according to German standard methods (DEV 2009).

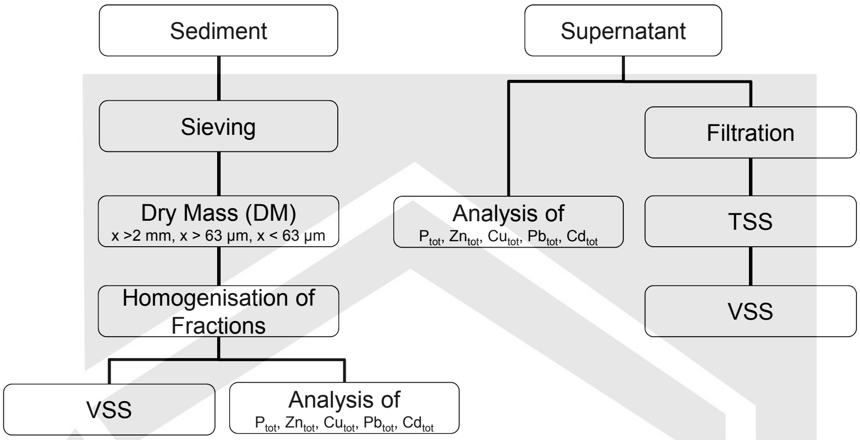


Figure 3: Scheme of the Laboratory procedure

# 3 RESULTS

## 3.1 Site specific Efficiency

The efficiency of settling tanks can basically be described by the removal of suspended solids, which are presumed to be a key parameter for storm water treatment. First, suspended solids concentration is the only parameter which can be influenced directly by storm water treatment technologies and secondly, suspended solids serve as carrier for several anthropogenic pollutants emerging in urban systems. Thus, an efficient reduction of emitted TSS loads means that pollutant loads are reduced similarly.

Table 2 summarizes the relevant mean data for the three treatment plants. Site mean concentrations (SMC) and surface loading rates (SLR) are based on 11 to 24 events. TSS concentrations in the clarifier overflow are indicated as $SMC_{TSS\_out}$.

Table 2: Mean values of surface loading, influent and effluent concentrations and load weighted efficiencies

| | $SLR_{max}$ in m/h | $SLR_{mean}$ in m/h | $SMC_{TSS\_in}$ in mg/l | $SMC_{TSS\_out}$ in mg/l | $\eta_{TSS\_}$ in % |
|---|---|---|---|---|---|
| CSS 1 | 1.5 | 0.6 | 146 | 70 | 68 |
| CSS 2 | 1.9 | 0.5 | 155 | 63 | 65 |
| SSS 1 | 5.6 | 1.9 | 134 | 64 | 49 |

Mean load weighted efficiencies ranged between 49 % and 68 %. The smallest value was calculated for SSS 1. Maximum surface loads which are shown in the second column of table 2, give a first explanation for this result. The averaged maximum surface load reaches 5.6 m/h and is far above the surface loads of the other plants. At SSS 1 the hydraulic control of the clarifier overflow did not work properly and although the plant was designed for a maximum surface load of 6 m/h distinctly higher values occurred frequently.

The site specific mean inflow concentrations of TSS varied only a little between 134 and 155 mg/l but more remarkable is that the SMC values in the clarifier overflows were rather constant ranging between 63 and 70 mg/l. This may indicate a limit with respect to the achievable concentration of TSS in the clarifier overflow of sedimentation tanks based on long-term average.

Besides the hydraulic conditions, the TSS influent concentrations affected the efficiency of the lamella settlers (s. paragraph 3.4). A closer look at the results gained for single events can help to check this assumption (s. table 3).

## 3.2 Efficiency based on Single Events

As mentioned in paragraph 2.1, parasite water influent caused that the settling chamber of SSS 1 was filled in the beginning of storm events. Hence, the storage capacity of the settling chamber has not been considered and the monitored suspended solid removal can be traced back on sedimentation solely. Therefore the data from SSS 1 are favorable to reveal basic coherencies. In table 3 the relevant data ordered by the maximum surface loading rate are listed.

Table 3: Event mean values of surface loading, influent and effluent concentrations, loads and weighted efficiencies for SSS 1

| Nr. | Date | $SLR_{max}$ in m/h | $SLR_{mean}$ in m/h | $EMC_{TSS\ in}$ in mg/l | $EMC_{TSS\ out}$ in mg/l | $L_{TSS\ in}$ in kg | $L_{TSS\ out}$ in kg | $\eta_{TSS}$ in % |
|---|---|---|---|---|---|---|---|---|
| PN 20 | 01.09.2008 | 12 | 2.7 | 129 | 99.7 | 594 | 460 | 23 |
| PN 30 | 23.07.2009 | 10.6 | 1.9 | 422 | 215 | 730 | 371 | 49 |
| PN 31 | 01.09.2009 | 9.1 | 3.8 | 120 | 85.9 | 1337 | 957 | 28 |
| PN 28 | 13.07.2009 | 7.3 | 4.1 | 117 | 84.4 | 1164 | 841 | 28 |
| PN 26 | 27.06.2009 | 6.5 | 2.2 | 343 | 140 | 1972 | 805 | 59 |
| PN 27 | 06.07.2009 | 6.5 | 2.3 | 237 | 117 | 332 | 163 | 51 |
| PN 17 | 01.08.2008 | 6.5 | 2.6 | 79.3 | 48.6 | 455 | 279 | 39 |
| PN 21 | 03.09.2008 | 6.3 | 1.7 | 99 | 49.9 | 302 | 152 | 50 |
| PN 29 | 17.07.2009 | 6.3 | 2.3 | 86.9 | 74.6 | 847 | 727 | 14 |
| PN 16 | 06.07.2008 | 5.7 | 2.1 | 254 | 110 | 962 | 417 | 57 |
| PN 18 | 08.08.2008 | 5.4 | 2.5 | 165 | 65.2 | 167 | 66 | 60 |
| PN 10 | 03.04.2008 | 5.2 | 1 | 171 | 69.4 | 483 | 196 | 59 |
| PN 9 | 17.03.2008 | 5.2 | 1.2 | 42.5 | 33.4 | 614 | 483 | 21 |
| PN 23 | 16.10.2008 | 5.2 | 1.7 | 131 | 61 | 1599 | 746 | 53 |
| PN 34 | 26.11.2009 | 4.7 | 1.4 | 176 | 64.3 | 2426 | 889 | 63 |
| PN 25 | 06.06.2009 | 4.7 | 1.6 | 187 | 85.1 | 1348 | 614 | 54 |
| PN 19 | 08.08.2008 | 4.7 | 1.8 | 71.6 | 40.4 | 698 | 393 | 44 |
| PN 11 | 09.04.2008 | 4.3 | 1.8 | 188 | 62.4 | 1967 | 652 | 67 |
| PN 15 | 03.07.2008 | 4.2 | 1.8 | 157 | 62 | 236 | 93 | 61 |
| PN 32 | 07.11.2009 | 3.7 | 1.2 | 50.7 | 34.9 | 321 | 221 | 31 |
| PN 33 | 14.11.2009 | 3.2 | 1.2 | 54.4 | 52.3 | 234 | 224 | 4 |
| PN 22 | 02.10.2008 | 2.6 | 0.9 | 126 | 40.4 | 211 | 68 | 68 |
| PN 12 | 16.04.2008 | 2.5 | 0.8 | 187 | 55.7 | 1252 | 373 | 70 |
| PN 24 | 22.10.2008 | 2.4 | 1.2 | 27.9 | 25.7 | 426 | 393 | 8 |

The influent concentrations covered a wide range from 28 to 422 mg/l and the surface loading rate varied from 0.8 to 12 m/h. As a result of the inter-relation of input concentration and prevailing hydraulic conditions in the settling chamber the calculated removal rates varied significantly between 4 and 70 %.

At a first glance, the expected relation between maximum surface loading rate and achievable efficiency becomes visible. However, the data include also events where the removal rate was very small even though the hydraulic loading of the system was small too. This is illustrated by the events PN 24 and PN 33.

Figure 4 shows the weak or even non existing correlation between the hydraulic conditions and the achievable effluent concentrations. While the mean surface loading rate is obviously not suitable to predict the effluent concentration, the maximum surface loading rate seems to be a relevant parameter influencing efficiency of the lamella settlers. A second parameter is certainly the grain size distribution of the solids that corresponds somehow with concentration and the settling velocity distribution.

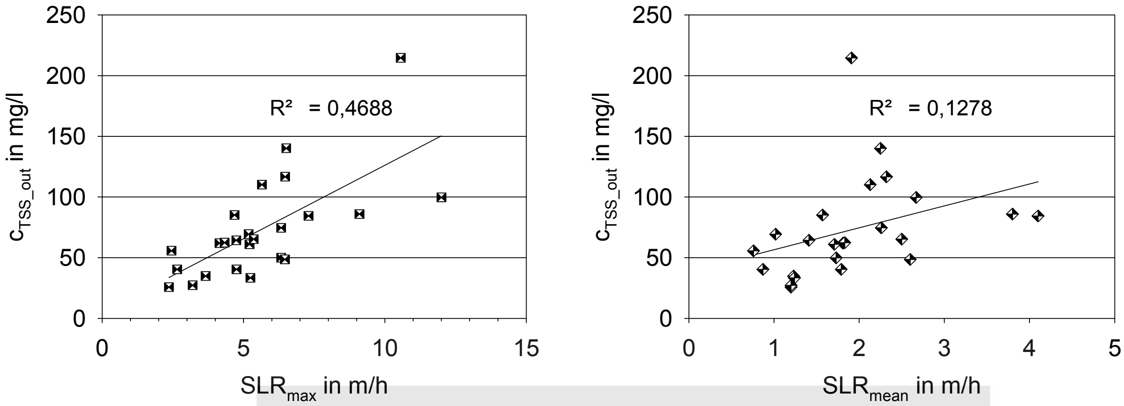


Figure 4: Correlation between $EMC_{TSS\_in}$ in the clarifier overflow and $SLR_{max}$ and $SLR_{mean}$ respectively

## 3.3 Properties of Suspended Solids

Applying the new sampling method opens the opportunity to characterize the solids in the influent and effluent of the lamella settler in regard to their grain size distribution, organic content and pollutant load. This information is vital for the interpretation of the above shown efficiencies and for the development of design recommendations.

In table 4 the results for CSS 2 and SSS 1 are compiled for two relevant grain size fractions:

- Fine solids covering the grain size distribution of clay and silt (< 63 µm)
- Coarse solids covering the grain size distribution of sand (> 63 to 2000 µm)

The row “In” subsumes the findings in the treatment plant influent were as “Out” stands for the results gained for the clarifier overflows. It has to be mentioned that the terms “clay and silt” or “sand” are only related to the grain size of particles as a result of the sieving analysis. They are not declaring anything about particles origin and properties. The fraction sand includes for instance both, sandy soil and the debris of vegetation in the grain size of sand.

Table 4: Solids and solid properties for CSS 2 and SSS 1

| | Mass in g | Portion in % | TSS in mg/l | VSS in % | $P_{tot}$ in mg/kg | $Zn_{tot}$ in mg/kg | $Cu_{tot}$ in mg/kg | $Pb_{tot}$ in mg/kg | $Cd_{tot}$ in mg/kg |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | CSS 2 | | | | |
| In < 63 µm | 30.9 | 69 | 97.4 | 38.3 | 6678 | 1402 | 573 | 131 | 1.21 |
| In > 63 µm | 20.3 | 31 | 63.2 | 75.7 | 3591 | 853 | 293 | 77.8 | 0.61 |
| Out < 63 µm | 12.3 | 82 | 46.0 | 33.1 | 6317 | 1606 | 607 | 153.9 | 1.26 |
| Out > 63 µm | 2.4 | 18 | 10.9 | 68.0 | 4202 | 1276 | 463 | 114.3 | 1.04 |
| | | | | | SSS 1 | | | | |
| In < 63 µm | 46.2 | 71 | 98.4 | 25.3 | 1819 | 1277 | 219 | 86.6 | 0.88 |
| In > 63 µm | 22.8 | 29 | 43.8 | 44.1 | 1721 | 1227 | 193 | 77.0 | 0.87 |
| Out< 63 µm | 17.1 | 79 | 55.8 | 26.9 | 1942 | 1853 | 236 | 98.0 | 0.90 |
| Out > 63 µm | 5.8 | 21 | 15.2 | 50.2 | 2022 | 2015 | 256 | 91.5 | 1.05 |

One important result shown in table 4 is that the share of the fine fraction in the influent of both treatment plants is high. This might be contributed to the grit traps which are installed in front of the settlers. Further studies carried out in separate sewer systems of Berlin (Fuchs et al. 2010) found that the portion of fine solids in the influent of central storm water treatment plants is always high, ranging between 70 and 90 %. Retention processes occurring in the catchment and in the sewer system itself result in a classification of the solids. This in turn result in a significant reduction of the transported masses and an accumulation of fine solids in the influent of the treatment plant. Thus the input concentrations give evidence about the grain size distribution and the settleability of the solids in the storm water runoff.

Apart from the grain size distribution the quality of the solids which can be expressed by the percentage of volatile suspended solids (VSS) is an important parameter for the prediction of the settelability of solids. In CSS 2 and SSS 1 particular high values, up to 71 % are determined for the sand fraction. For the combined system (CSS 2) particulate waste water constituents, mainly toilet paper, are responsible for this. In the separate system (SSS 1) the organic particles result from vegetation debris. Independently of the source high organic contents are reducing the efficiency of any sedimentation plant due to their low density.

The organic content is causing a second effect because it changes the particle size related pollutant loading of solids. Considering mineral particles only, the fine and coarse fraction can be clearly distinguished according to the pollutant load. The fine particles are then the main pollutant carrier. The charged surfaces of organic particles are covering the particle size effect so that coarse and fine particles carry almost the same pollutant load. A special aspect has to be mentioned for CSS 2. Despite the fact that organic content of the coarse particles in CSS 2 was much higher than at SSS 1, the pollutant loading of the coarse material is significantly lower. This apparent discrepancy can be explained by the quality of the organic material. The VSS in the combined system overflow mainly consist of cellulose fibers with very low adsorption capacity.

## 3.4 Multivariate Linear Regression Analysis

A regression model was developed which combines both input information of flow conditions and EMC for describing the dependent outflow concentration. The regression analysis finally yields to equation 1, which combines the maximum flow rate, $q_{A\_max}$, and $EMC_{TSS\_in}$, as the two relevant parameters affecting significantly the performance of the plant.

$$EMC_{TSS\_out} = \exp\left[0{,}67 \ln\left(EMC_{TSS\_in}\right) + 0{,}56 \ln\left(q_{A\_max}\right)\right] \qquad \text{Eq. 1}$$

In regard to the resulting TSS concentration in the clarifier overflow, the representative concentration in the influent seemed to be more significant compared to the maximum flow in the sedimentation tank. This becomes apparent by means of the standardized coefficients of the input variables at which the coefficient of the $EMC_{TSS\_in}$ variable is about three times higher compared to the corresponding value of $q_{A\_max}$.

In figure 5 the modeled values of TSS concentrations in the clarifier overflow are plotted against the values of the field measurements.

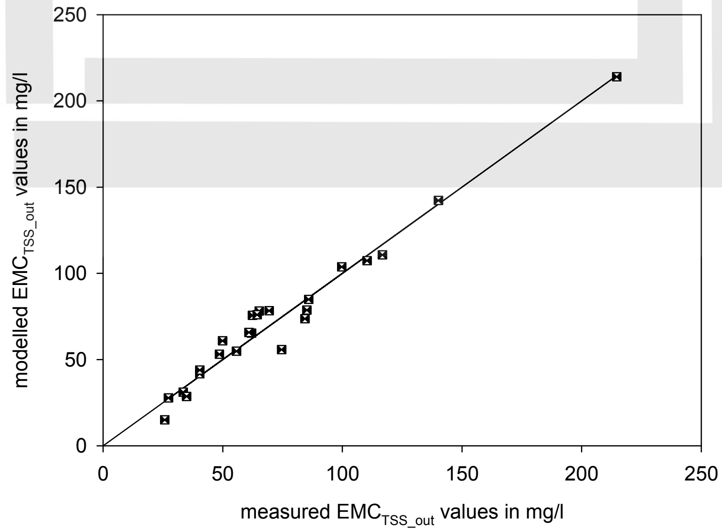


Figure 5: Modeled TSS concentrations of the clarifier overflow plotted against the measured values

The graph illustrates the quality of the regression model and certifies the significance of the chosen input variables. The regression analysis thus confirmes the assumption that influent concentration has a major effect on the performance of the treatment plant. The solid concentration bears information about the distribution of the suspended particles. In this context, low concentrations indicate a high percentage of fine particles which is associated with a decayed settleability and vice versa. Also previous investigations (Aiguier et al., 1995) dealing with the settleability of storm water solids, attested that higher settling velocities are associated by higher initial solids concentrations.

The application of equation 1 yields to the chart illustrated in Figure 6. The curves are indicating the calculated settler performance depending on the maximum surface loading rate and representative TSS influent concentration.

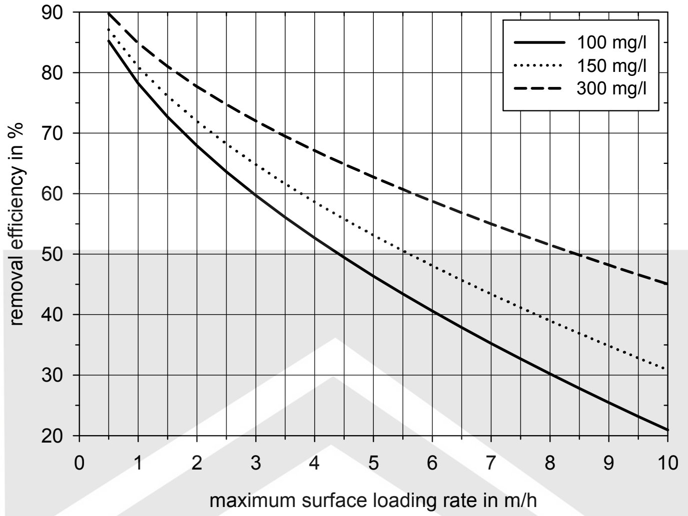


Figure 6: Calculated performance of lamellae settler depending on $SLR_{max}$ and TSS influent concentration (SMC)

It has to be kept in mind that the performance curves are generated in the course of an analytical method and therefore represent the whole range of possible efficiencies. In practice the efficiency of the sedimentation process realized in technical structures is characterized by an upper limit which can be described by the achievable effluent concentrations. The data gained in this study converge to a long-term effluent concentration from 63 to 70 mg/l. Assuming a high influent concentration of 300 mg/l this would result in around 80 % removal efficiency. In fact it can be stated that 80 % solid removal pose a long-term maximum value.

## 4 DESIGN AND CONSTRUCTION

A primary aim of storm water treatment in combined and separate sewer systems is a significant and reliable reduction of the emitted suspended solid loads. This requires a limitation of the maximum surface loading rate.

Assuming an influent concentration of 150 mg/l, which can be considered to reflect average conditions (Brombach & Fuchs 2003), the achievable annual TSS removal can be calculated on the basis of figure 6 and an appropriated design value for the maximum surface loading rate can be derived. For this purpose critical runoff rates has to be taken into account.

A standard value for German storm water tanks is 15 l/(s·ha). It is assumed that based on this value 75 % of the annual runoff can be treated transporting 90 % of the annual solid load from the catchment. Figure 7 shows the result of these assumptions for three critical runoff rates. The annual TSS removal rate varies as a function of the maximum surface loading rate and critical runoff rate treated.

If 50 % is defined as minimum long-term requirement for the solid removal the design surface loading rate for standard conditions can be deduced from figure 7. It is the point where the 50 % line cuts the curve for 15 l/(s·ha).

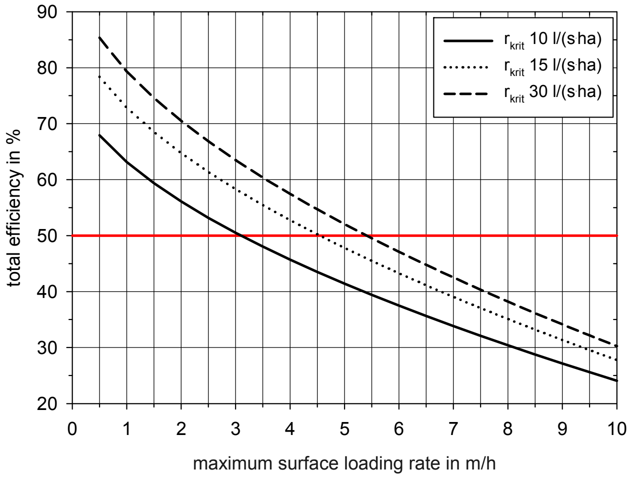


Figure 7: Annual TSS removal over maximum surface loading rate (SLR), ($SMC_{TSS}$) of 150 mg/l

In order to make sure that the minimum requirement according TSS removal can be realized the recommendation for the maximum surface loading rate is 4 m/h. At this design value the effect of remobilization is minimized and as the majority of surface loads will be much lower according to the frequency distribution of storm events the efficiency of the lamella settler can reach up 70%.

Beyond a limitation of the surface loading a prerequisite for an effective operation of any sedimentation tank is an even distributed flow through the settling chamber. One advantage of counter-current lamella settlers is that the water is forced in a controlled upward flow through the lamella. To utilize the advantage of lamella settlers, which is first of all the significantly extended surface area, it has to be secured that the calculated surface area is loaded equally and that the energy input is minimized.

One requirement for this is, that the launders are arranged in a way that the flow pathways are not too long and not unequally and that they are leveled very thoroughly. A further relevant issue is that the energy of the incoming storm water has to be effectively dissipated. Taking into account how fragile the hydraulic conditions in the lamella are, it becomes clear that any preferential flow or turbulence beyond the lamella will affect the sedimentation process negatively.

## 5 CONCLUSION

The efficiency of conventional storm water tanks is weak especially if fine particles are considered to be the target of storm water treatment. Lamella settler are a suitable technology to upgrade existing plants or to be included in new constructions. In the latter case they have a considerable economic potential because they help to reduce the volume needed to be built. Moreover even if lamella settlers are used, the maximum surface loading rate has to be limited. A value of 4 m/h has been found suitable. Furthermore it has to be noticed that the construction of lamella settlers is demanding and requires specific additional elements.

Beyond these practical aspects the study highlights some fundamental issues which are of general importance for storm water treatment. In order to develop effective technologies or to assess the environmental effect of storm water treatment systems, it is necessary to consider the traditional parameter TSS in a differentiated way. The grain size distribution and the organic content of the particles are the most important parameters. In this regard three fractions of urban solids should be considered:

- Fine particles in the grain size of clay and silt (< 0.063 mm). They are always highly polluted and hard to settle.
- Coarse mineral particles in the grain size of sand and gravel (> 0.063 mm). They are always less or even unpolluted and quite easy to settle.
- Coarse organic particles (> 0.063 mm) which are carrying a considerable pollutant load due to their organic surfaces. They do not behave conservatory in the sewer systems but are subject of constant transformation processes changing them from formally coarse to fine particles.

In regard to surface water protection the removal of fine particles and when present the organic coarse fraction can be seen as the primary aim of storm water treatment.

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