



HAL
open science

Innovative use of lamella clarifiers for central stormwater treatment in separate sewer systems

G. Weiss

► **To cite this version:**

G. Weiss. Innovative use of lamella clarifiers for central stormwater treatment in separate sewer systems. Novatech 2013 - 8ème Conférence internationale sur les techniques et stratégies durables pour la gestion des eaux urbaines par temps de pluie / 8th International Conference on planning and technologies for sustainable management of Water in the City, Jun 2013, Lyon, France. <hal-03303555>

HAL Id: hal-03303555

<https://hal.science/hal-03303555v1>

Submitted on 28 Jul 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Innovative use of lamella clarifiers for central storm-water treatment in separate sewer systems

Utilisation innovante des décanteurs lamellaires pour le traitement des eaux pluviales dans les réseaux séparatifs

Gebhard Weiss

Umwelt- und Fluid-Technik Dr. H. Brombach GmbH, 97980 Bad Mergentheim, Germany g.weiss@uft-brombach.de

RÉSUMÉ

Ces dernières années, les décanteurs lamellaires sont utilisés pour le traitement des eaux pluviales par sédimentation. Au lieu d'installer un grand nombre de lamelles de décantation dans un bassin de sédimentation, une solution innovante pour les réseaux d'assainissement séparatifs est proposée. Les eaux pluviales sont stockées dans un bassin lors d'un évènement pluvieux et sont traitées à débit faible, mais continu, dans un décanteur lamellaire. L'avantage est que le faible débit à traiter ne nécessite qu'une unité de décantation lamellaire à faible encombrement ayant, tout de même, une bonne efficacité de sédimentation. En outre, les volumes de stockage existants peuvent être comptabilisés et utilisés, par exemple des conduites d'eaux pluviales à grands diamètres. Cette solution permet une grande flexibilité dans l'implantation des ouvrages. D'autre part, le volume d'eau pluviale qui va être traité à la station d'épuration après chaque pluie est minimisé.

Pour démontrer l'efficacité du traitement, une méthode de simulation est proposée comparant la solution innovante à une solution conventionnelle de bassin de sédimentation dimensionné suivant les directives techniques allemandes actuelles. Le volume annuel des eaux traitées ou plus directement la charge polluante déversée à la rivière, exprimée en MES, peuvent être utilisés comme variables.

Enfin, un exemple de projet est présenté.

ABSTRACT

In the past years, lamella settlers have been used as devices for treatment by sedimentation also for storm water. Instead of just equipping a sedimentation basin with numerous lamella modules, an innovative approach for traditional separate systems is proposed. Basically, storm water is stored in a basin or tank during a rain event, while treatment is done in a small but continuously operated lamella clarifier unit. The advantages are a low throughput flow of the lamella clarifier, yielding a small-footprint unit having a good efficiency, moreover the possible use of existing storage volume, e.g. in an existing storm sewer, and also the structural flexibility of the arrangement. Finally, also the water volume which is fed together with the sludge to a treatment plant may be minimized.

A simulation method is proposed in order to assess an equivalent degree of stormwater treatment, either by achieving an equal annual volume of treated storm water or, more directly, an equal amount of spilled pollutant load, expressed as Total Suspended Solids (TSS), both if compared with a conventional settling tank according to current German design rules.

Finally, a project example is also demonstrated.

KEYWORDS

Lamella clarifier, Sedimentation tank, Separate sewer system, Settling efficiency

1 INTRODUCTION

In several European countries as well as overseas, recent urban drainage masterplans make thorough use of the separate sewer system. In particular, alternative de-central drainage systems applying local soil infiltration and on-site detention are preferred. In Germany, a new water act (WHG 2010) has pointed out this preference nationwide. One could easily think that “classic” central treatment structures such as stormwater tanks are out of fashion – if there were not hundreds of square kilometres of sealed surface in towns and cities and also thousands of kilometres of sewers. Theoretically, it would be possible to convert such existing structures in decentral systems, but this would be rarely economic, even if seen on a very long run.

Anyhow, also traditional separate sewer systems need storm water treatment in many cases, particularly if the surfaces are considerably polluted and/or the receiving waters are very sensitive. The current German state-of-the-art is given by DWA guidelines, namely DWA-M 153 (2007) and DWA-A 166 (2010). A new comprehensive paper DWA-A 102 which includes also combined sewer systems is currently in process (Schmitt 2012). Other guidelines define an immission-oriented approach based on the sensitivity of the receiving waters, e.g. BWK-M3 (2001)

In the following, traditional separate systems are considered, which are predominating for historical reasons in the North and East of Germany. These systems feature long storm sewers in parallel to sanitary sewers. Usually, there is no stormwater treatment at all, i.e. the storm sewer runs straight away to the closest watercourse. According to DWA-M 153, however, treatment of the stormwater is required in many cases, e.g. at very small creeks or in water protection areas. M 153 covers a portfolio of feasible treatment structures and methods. Centrally located sedimentation basins or tanks of traditional design with or without permanent water filling may be regarded as a standard, in many cases built as concrete structures. For very sensitive sites, soil filters are preferred.

In the present paper, we try to expand the portfolio of solutions for stormwater treatment by application of the lamella clarifier as an innovative technique. In process engineering, it is a well-known sedimentation device; cf. e.g. Schade and Sapulak (1984). Several types are commercially available, also as tilted-plate or tube settlers. Most clarifiers of this kind are of counter-flow type, i.e. the water passes between the inclined plates (lamellae) or honeycomb modules upwardly while the settling particles collect on the surface beneath and slide finally down. Cross-flow settlers are also used; see e.g. Vasquez et al. (2010). In the following, the terms “lamella clarifier” or “lamella settler” are used regardless of the type (Fig. 1).

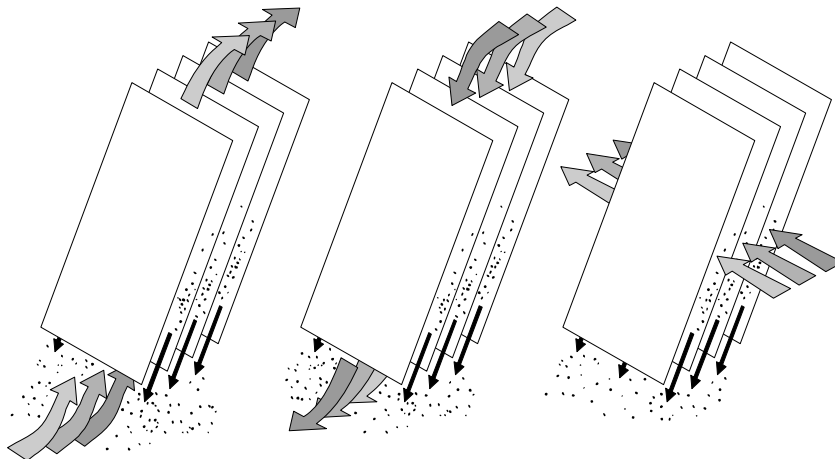


Fig. 1. Lamella settlers of counter-flow, parallel flow and cross-flow type

There have been some applications for stormwater treatment in separate and also in combined systems, see e.g. Takayanagi et al. (1996), Andritschke (2010), Fuchs et al. (2010), Schaffner et al. (2010), Boogaard et al. (2010). The use of flocculation agents, as proposed by some authors such as Bridoux et al. (1998), is not investigated in the following.

The paper proposes a method to show up the equivalence of a lamella clarifier unit to a classic sedimentation tank. It is first necessary to discuss briefly the sizing procedure of sedimentation structures (Chapter 2). Subsequently, the new concept will be introduced (Chapter 3).

2 CURRENT SIZING RULES FOR SEDIMENTATION TANKS

In the following, German practice for the design of sedimentation tanks in separate systems is shown. In other countries, of course, different sizing rules may be applicable.

A rectangular sedimentation basin of traditional design is shown in Fig. 2. For sizing of the structure dimensions according to the guideline DWA-M 153 (2007), a straight throughflow $Q_{\text{krit}} = r_{\text{krit}} \cdot A_U$ is assumed where A_U is the impervious catchment surface in ha and r_{krit} is the design storm intensity which ranges between 15 l/(s·ha) for less sensitive and 45 l/(s·ha) for more sensitive receiving waters. When this flow is passing the tank having the length L and width B , the surficial loading $q_A = Q_{\text{krit}} / (L \cdot B)$ should not exceed 10 m/h to ensure good sedimentation. Moreover, certain proportions of the sedimentation chamber should be respected (DWA-A 166, 2010) to ensure parallel throughflow without backwater zones. The minimum water depth should be $H = 2$ m. Any storage effect of the tank, however, is neglected in this sizing procedure.

The smallest possible sedimentation chamber for which all requirements are met strictly has $L = 20$ m, $B = 4.44$ m and $H = 2.0$ m, yielding a volume of $V = 178$ m³. This would be sufficient to serve a rather large catchment having an impervious surface of $A_U = 16.47$ ha at $r_{\text{krit}} = 15$ l/(s·ha).

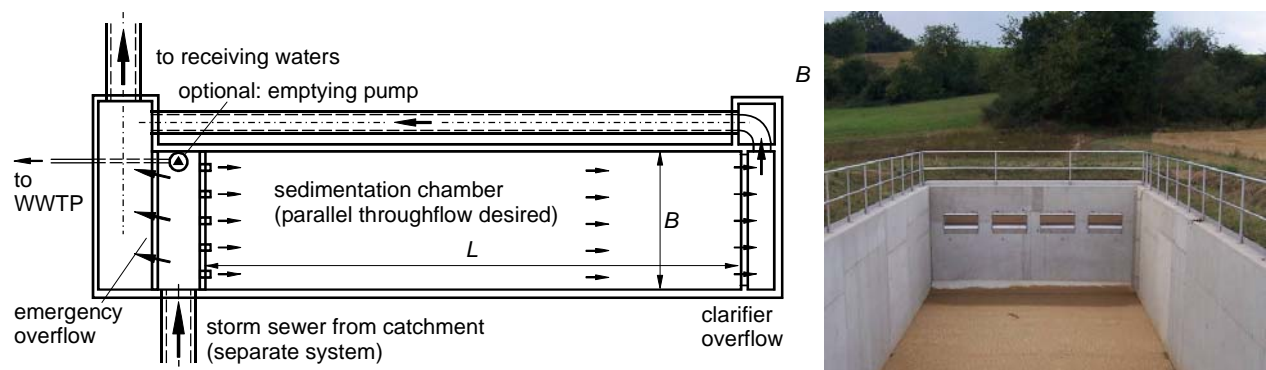


Fig. 2: Typical design of a rectangular sedimentation tank (Photo: UFT)

An additional emergency overflow for strong inflows avoids remobilization of already settled sludge. Both overflows should be carefully adjusted for proper hydraulic performance. For details see Brombach, Weiss and Pisano (2008).

It is currently preferred that sedimentation basins are emptied after each storm event, e.g. the clear water zone to the receiving waters and the sludge zone to a sanitary sewer and a treatment plant. To keep the water permanently in the structure, as frequently used in former times, is disliked today because of the danger of re-solution of heavy metals from the sludge; cf. e.g. LfUBW (2008).

Groundwater-borne infiltration inflow which causes a permanent flow in the storm sewer could be problematic. Misconnections of sanitary sewage are particularly detrimental for any separate sewer system. These items are not elaborated more in detail here for brevity.

The described dimension procedure has, however, some remaining inconsistencies:

- What to do in small catchments of only some hectares of sealed surface – a very frequent case? To build a large sedimentation tank of 178 m³ under strict compliance to all guidelines, as described, would not be economic for less than 16.5 ha.
- The guidelines do not make any statements how to empty a sedimentation tank after a storm event. If the whole volume is fed to the treatment plant after every event, this would be a rather great deal of the annual runoff volume – equivalent to the runoff volume relations in a combined sewer system. This is not desired in a separate system.
- A very big disadvantage of the design procedure is the fact that the storage effect of stormwater in the tank (and also possibly in a large storm sewer system) is utterly disregarded, even if this effect will greatly reduce the frequency of overflow events and also the annual pollutant loads spilled from the sedimentation structure into the river.

3 INNOVATIVE COMBINATION OF STORAGE AND LAMELLA CLARIFIER

3.1 Concept

It is a straightforward approach to equip or retrofit sedimentation tanks of traditional design with lamella clarifiers in order to enhance their efficiency and/or to minimize the necessary structure volume. But in many cases, this requires considerable lamella settler volume and hence considerable costs with respect to the comparatively high design throughflow of the tank. For a more general application in stormwater treatment, it is reasonable not to keep the approach of steady throughflow, but to search for a solution which accounts also for storage effects. As basic idea, the proposed concept keeps "storage" and "treatment" as main processes in separate structures. It has the following features:

- Storage volume, either in a stormwater tank or in the storm sewer, which is filled up during a rain event. In contrast to a conventional sedimentation tank as described above, the shape and proportions of the volume are irrelevant. Oversized sewers or cheap-to-build open ponds are applicable.
- A lamella clarifier is serving as treatment unit, located in a separate small manhole. It is designed for a rather small, yet continuous, throughflow. The lamella clarifier could be made from commercial honeycomb modules. It may be equipped by a mechanism for automatic cleaning as an additional feature.
- This allows a flexible arrangement for any project, particularly if the lamella settler is fed by a pump. If some level difference is available, gravity feeding may also be used.

This arrangement is shown schematically in Fig. 3 (bottom). In many cases, storage at no extra costs is available in the storm sewer itself. In long sewers with low slopes, frequently several 100 m³ of storage may be activated, especially because no basement drainages are connected and backing-up of the storm water will rarely cause any problems. The sewer also needs an emergency overflow to the receiving waters for release of very strong inflows during storms. A pump which may be located in the sewer itself or in a separate manhole is feeding the lamella clarifier. The sludge from the clarifier structure may be drained to a sanitary sewer by a shutoff valve or by a second pump.

Sedimentation efficiency of the lamella clarifier is governed mainly by the size of the lamellae surface on which sedimentation takes place, dependent on the chosen throughflow. A lamella settler features a large sedimentation area in a small volume which provides a good efficiency. The surficial loading may be chosen rather low, say, 3 – 4 m/h compared with 10 m/h in a traditional sedimentation tank. Since the water is pumped, no overcharge can take place, even not during strong storms.

3.2 Dimensioning by comparative quantity-quality simulation

The new concept is not yet covered by technical rules. Anyhow, the components have to be sized properly, which requires a method to show up equivalence to a conventional solution. The tool which has been applied is a comparative numerical quantity-quality simulation which automatically accounts for storage effects in both cases of Fig. 3. To show an equivalent level of water protection, the following approaches may be used:

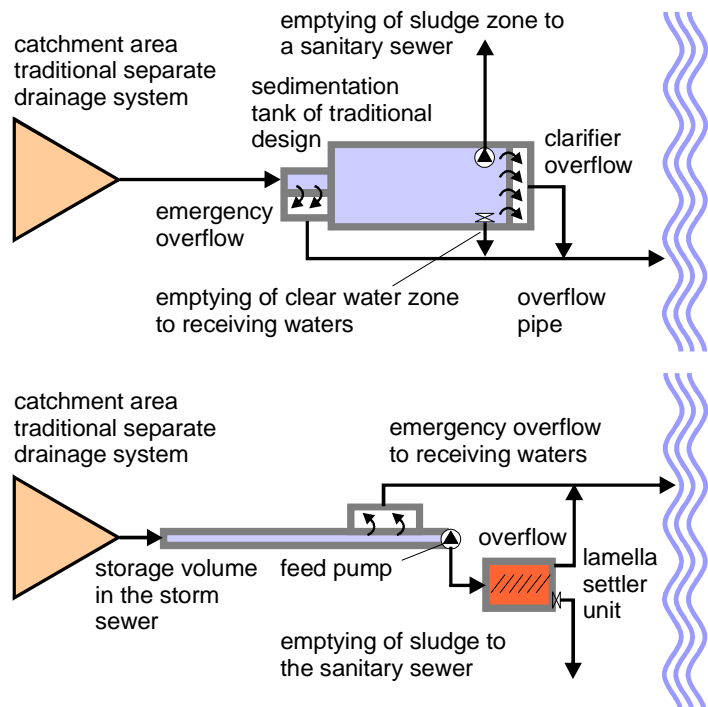


Fig. 3: Top: Traditional sedimentation tank which is emptied after each storm event. Bottom: Alternative concept where the storm sewer is used as a storage volume, plus a lamella clarifier unit as treatment device.

- Proof of an equal annual water volume which is treated by the lamella clarifier or in a conventional sedimentation tank. This approach assumes that the treatment process is equally effective in both structures.
- Proof of an equal pollutant load in both systems which is spilled into the receiving waters per year, e.g. as kg of total suspended solids (TSS). This approach needs some additional assumptions, such as on the concentration of TSS and on the sedimentation efficiency for this material.

There are some commercial quantity-quality simulation tools on the market, e.g. KOSIM by the German supplier itwh Hannover, which are widely used for optimization of combined sewer systems. This software has also been applied here. It allows the use of synthetic 30-year storm series in 5-minute intervals. The following effects are accounted for in order to simulate the annual flow volumes properly:

- Only the storm runoff in an “ideal” separate system without any dry weather flow is modelled. Both systems receive the same input.
- The hydraulics of the overflow weirs (clarifier and emergency overflow) must be simulated in detailed form (proper head-discharge relationships and weir levels included). This is essential for correct volume calculation since the water passing the settling tank by the clarifier overflow is regarded as treated while water spilled by the emergency overflow is not.
- Emptying of both the conventional sedimentation tank and the lamella clarifier must be simulated correctly. This requires some tricks since the used simulation model normally does not allow for discontinuous emptying of structures. Additionally, filling and emptying of the lamella clarifier volume and also emptying of sludge from the storage volume are accounted for.

As direct simulation results, only the water volumes and flows are regarded since KOSIM does not calculate the TSS as standard pollutant parameter. This allows a volume balance for both systems. The storage volume and the steady throughflow through the lamella settler are the key properties sought. By some simulation runs, these may be sized such that the simulation yields the desired equal annual volume of treated water compared with a conventional sedimentation tank.

3.3 Steady-state sedimentation efficiency of a lamella settler

For the desired determination of TSS loads, an important part of the model is to describe the steady-flow separation efficiency η of the lamella settler. η is defined as concentration ratio, $\eta = 1 - C_{\text{over}}/C_{\text{in}}$ where C_{over} is the overflow and C_{in} the inflow TSS concentration. If we assume ideal sediment with a uniform settling velocity v_s , η will increase with increasing v_s and with decreasing surficial loading q_A . One such relationship is the well-known Hazen formula for settling tanks where $\eta = \min(1, v_s/q_A)$ (blue dashed line in Fig. 4). However, own model tests on lamella settlers (not yet published) revealed that the Hazen relationship tends to overestimate the efficiency by far. The following functional relationship was obtained, where the surficial loading $q_A = Q_{\text{over}}/A_{\text{proj}}$ is calculated using the vertical plan-view projection area A_{proj} of the inclined surface of the lamella settler:

$$\eta = \frac{1}{40 \left(\frac{q_A}{v_s} \right)^3 + 1} \quad \text{Eq. (1)}$$

Eq. (1) is a “robust” approach which deliberately tends to underestimate the settling efficiency, accounting for effects like backmixing of already settled sludge which slides down in a counter-flow lamella clarifier and mixing again with the inflow, as well as irregular throughflow. The relationship is shown in Fig. 4. Similar steady-flow tests of prototype-size lamella separators have been reported by Boogaard et al. (2010) which used a different evaluation method. Since their separators were of different type (cross-flow) and had smaller lamella spacing, the differences in the data cannot be discussed here in detail. At least for smaller values of q_A/v_s , the same order of magnitude is observed for η .

The comparing simulation method from Chapter 3.2 needs a similar formula valid for the conventional settling basin. Since the sedimentation process follows the same physical conditions and theory in a basin as in a lamella settler, Eq. (1) is applied for both devices. This essential issue cannot be elaborated further here for brevity. It was verified also using the (rather scarce) literature data on steady-flow efficiency of sedimentation tanks (not shown here, either). For the sedimentation tank, the surficial loading is computed as $q_A = Q_{\text{over}}/(L \cdot B)$. The “pessimistic” Eq. (1) accounts for non-parallel flow, back-water zones and oscillating flow patterns in many settling basins. Moreover, due to the comparing

approach, possible errors in the assumed functional relationships may compensate for each other, at least partially.

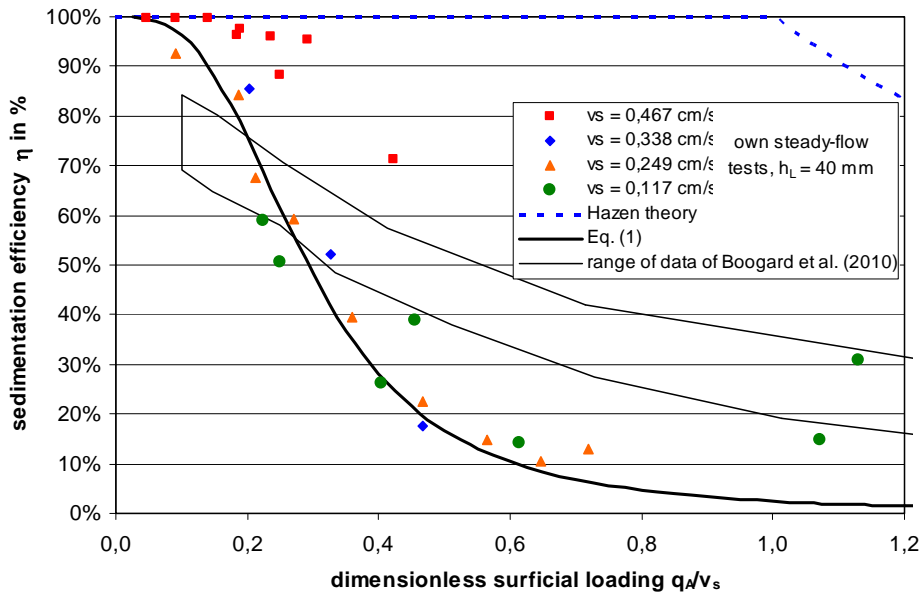


Fig. 4: Steady-flow settling efficiency relationships for lamella settlers. The data points are results of own investigations, using plastics granulate and salt water with varying density to gain low settling velocities.

3.4 Balance of total suspended solids

For determination of the TSS load, some additional assumptions had to be made:

- The storm runoff from the catchment has a constant TSS concentration of $C_{in} = 141 \text{ mg/l}$, a median value cited in Fuchs, Brombach and Weiß (2004) which seems reasonable for a comparison.
- The settleable solids in the storm water are characterized by a range of their settling velocity v_s . Lacking a “typical” distribution curve for sediments in a storm sewer, we used a v_s distribution for “light” sediments from combined sewer overflows, such as used in LfUBW (1997) for the design of vortex separators as another sedimentation structure. This allows “fractioning” of the sediment. Any fraction is characterized by a distinct v_s value, e.g. the uppermost 5 % of said 141 mg/l = 7.05 mg/l have $v_s = 1.227 \text{ cm/s}$, the next 5 % = 7.05 mg/l $v_s = 0.887 \text{ cm/s}$, etc.

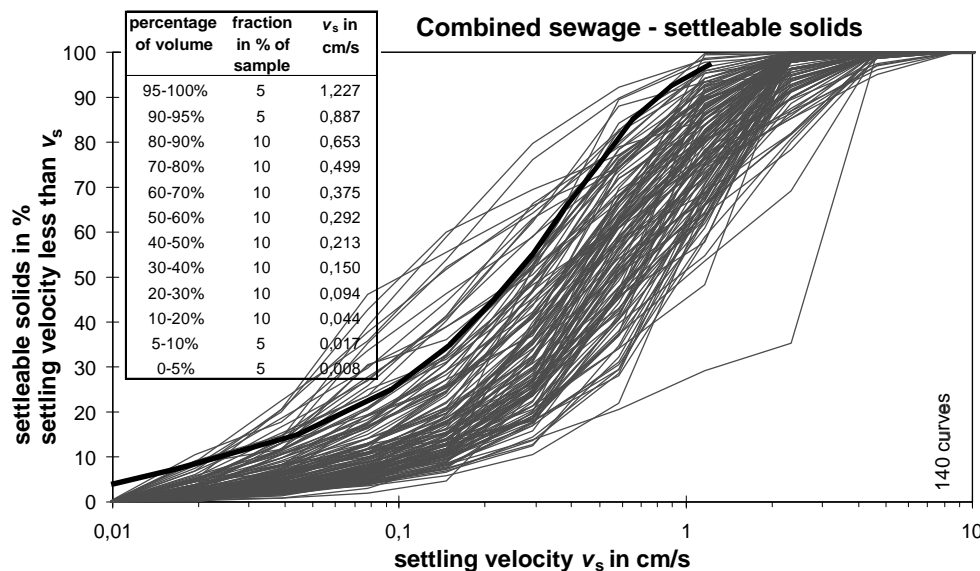


Fig. 5. Typical range of settling velocity distributions of combined sewer overflow sediments (cf. LfUBW 1997). The black curve characterizes “light” sediment. In the present study, it is assumed also to represent the sediment in storm runoff from separate systems.

- The overflow TSS concentration C_{over} of any sediment fraction is determined using the steady-flow settling efficiency η determined from Eq. (1) by $C_{over} = C_{in} \cdot (1 - \eta)$ where C_{in} is the inflow TSS concentration of this fraction as shown above.

The TSS load evaluation routine, finally, combines all these approaches with the simulation results. It calculates both for the settling basin as for the lamella settler from the simulated inflow $Q_{in}(t)$ the cur-

rent surficial loading $q_A(t)$, yielding q_A/v_s for each sediment fraction and $\eta(t)$ from Eq. (1). Weighing over the fractions and integration over time finally allows computation of the overflow TSS load. The difference to the inflow load is the settled portion of TSS which is removed from the system during tank emptying. Applying this procedure, it is possible to choose the dimensioning data of the combination storage plus lamella separator such that the desired equal spilled annual TSS load can be obtained, indicating a technical solution equivalent to a conventionally sized settling tank.

3.5 Typical results

We have made some comparing calculations to show up a typical relationship between the storage volume (e.g. in the storm sewer) and the necessary lamella settler throughflow. The reference base is a classic sedimentation basin as described in Chapter 2 of $V = 178 \text{ m}^3$ in a catchment of $A_U = 16.47 \text{ ha}$ of sealed surface. This is a specific volume of $V_S = 10.8 \text{ m}^3/\text{ha}$. For the alternative concept, the storage volume has been chosen as a variable in the simulation. For any chosen volume, the lamella settler throughflow was varied such that either the criterion “equal annual treated storm water volume in m^3/a ” or, alternatively, “equal annual spilled TSS load in kg/a ” was met.

The result is shown in Fig. 6 where flow and volume were standardized as per hectare of sealed surface. This graphics may be read as such: If e.g. a big storm sewer may be used as a storage which just yields this specific volume of $10.8 \text{ m}^3/\text{h}$ (dashed line), a lamella clarifier should be run with a design flow calculated from a storm intensity of around $12.3 \text{ l}/(\text{s}\cdot\text{ha})$ if the criterion “equal annual treated storm water volume” should be kept, while around $4.6 \text{ l}/(\text{s}\cdot\text{ha})$ or even $3.1 \text{ l}/(\text{s}\cdot\text{ha})$ are sufficient if “equal spilled TSS load” is applied, when the surficial loading is chosen as $4 \text{ m}/\text{h}$ or $3 \text{ m}/\text{h}$, respectively. Larger volumes require smaller flows, and vice-versa.

The biggest advantage of a simulation approach, of course, is an adaption of project-specific data and local conditions, e.g. a storm series, which need not be valid elsewhere, too. Thus, the mentioned results may be transferred to other situations only conditionally.

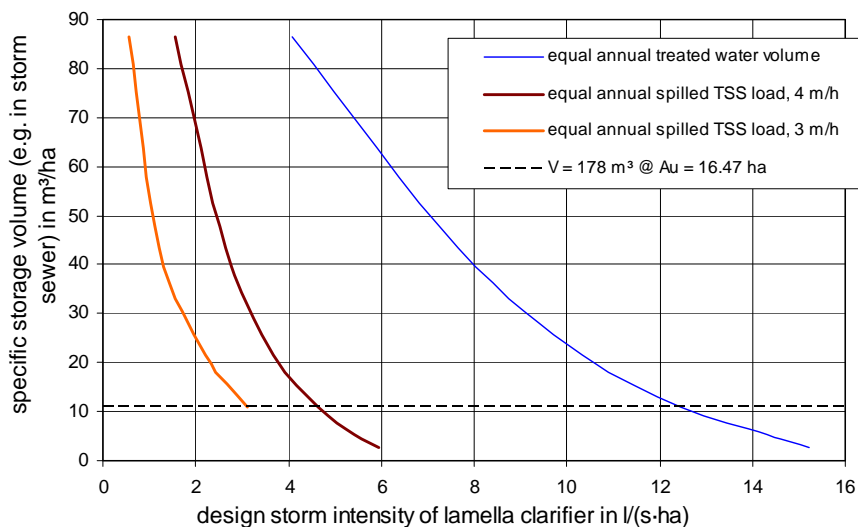


Fig. 6: Design storm intensity of the lamella settler dependent on the storage volume. For comparison, the surface loading was chosen as $3 \text{ m}/\text{h}$ and $4 \text{ m}/\text{h}$, respectively.

The first noticeable result is that the criterion “equal spilled TSS load” which accounts for the settling effect yields more favourable results as if only the water volumes are considered.

The curves for “equal spilled TSS load” on the left side are rather steep, indicating that it is more economic to increase the lamella clarifier throughflow than the storage volume if both properties are free to choose. If, as mentioned above, the storage volume upstream of the lamella clarifier is chosen as large as a conventional settling basin, $10.8 \text{ m}^3/\text{ha}$, the necessary storm intensity of $4.6 \text{ l}/(\text{s}\cdot\text{ha})$ yields less than $1/3$ of the design throughflow of the conventional basin, designed with $r_{\text{krit}} = 15 \text{ l}/(\text{s}\cdot\text{ha})$.

Choosing $3 \text{ m}/\text{h}$ rather than $4 \text{ m}/\text{h}$ as surficial loading of the lamellae may be efficient, too, since then the lamella throughput (and also the feeding pump and pipe work) may be chosen considerably smaller even if a larger settler volume is required to achieve $q_A = 3 \text{ m}/\text{h}$. If the criterion “equal treated water volume” is applied, the chosen surficial load in the lamella settler is of no influence at all – provided that an equally high settling efficiency as in the settling basin is reached.

The mentioned concept may also be used with advantage in special situations, e.g. enlargement of an

existing industrial area where a settling tank is already in operation and should be enlarged, too. Use of a lamella clarifier may make this redundant.

4 CONCLUSION AND ASSESSMENT OF RESULTS

The proposed concept of storage volume plus a small lamella clarifier is a new and innovative approach for central stormwater treatment in separate sewer systems. Compared with current German technical rules, it allows for the first time to account for storage effects. Existing storage volume may be used, e.g. in long storm sewers. Missing volume may be built in cheap way, e.g. as open ponds. In the first place, the concept does not yield large volume savings, but cost savings are possible due to cheaper construction.

The lamella clarifier throughput usually may be chosen considerably smaller than the design flow of a sedimentation tank. Small lamella units will be sufficient, particularly where ample sewer storage volume is available. The water volume which is fed to the sanitary sewer while emptying the treatment units after a storm is also balanced. Solutions may be found which minimize this volume.

The arrangement is rather flexible. Cost-effective solutions may be found where the described simulation is performed taking into account the project-specific conditions.

A critical assessment reveals that some of the approaches and assumptions may be sensitive, i.e. if the input data are changed slightly, the result may change significantly. This may be the case for the sedimentation approach, in particular for curves such as in Fig. 4, where the data currently available are not very reliable. Here some basic research is still needed in future. Anyhow, it is pointed out that the approaches are chosen carefully, in order not to over-estimate the sedimentation effect. Moreover, a comparison between two similar systems is evaluated rather than an absolute value. Thus, possible errors are made twice and may compensate each other.

5 PROJECT EXAMPLE

Finally, a project example is introduced which went into operation in 2011. For a residential and commercial area, completely drained by a traditional existing separate system, stormwater treatment got necessary due to sensitive receiving waters which passed also a drinking water protection area. According to conventional design rules, a settling tank of around 250 m³ would have been required. The existing storm sewer system had low slopes and consequently large pipe diameters. It was thus possible to back up around 1000 m³ as storage volume. It could be shown that two small lamella settler units with a throughflow of 16 l/s each were sufficient. In addition, a new overflow manhole and an additional pump manhole were needed which were built close to the existing outflow sewer. The lamella settlers are located in two manholes of 2 x 2 m. All new ancillary structures were ready-made concrete shafts.

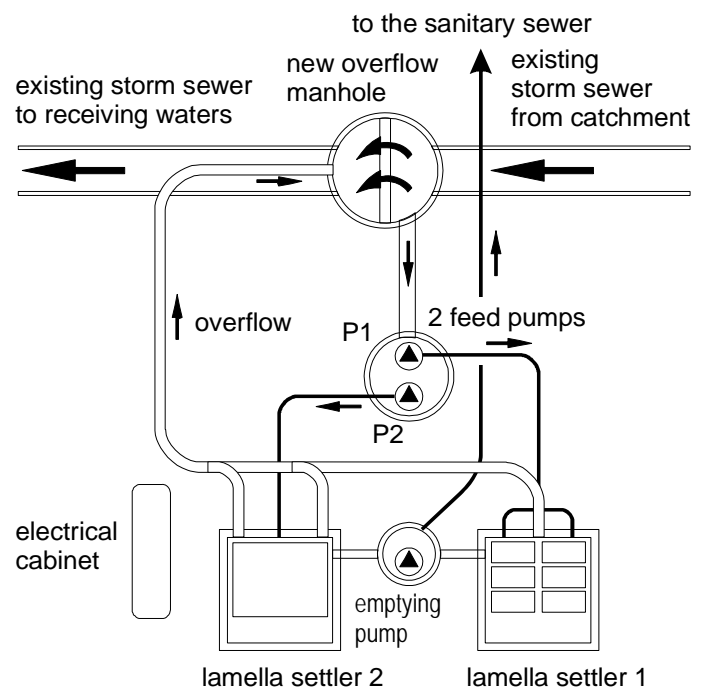


Fig. 7: Plan view of the project example

Above the lamella modules which are arranged as six packets, an overflow gutter system ensures smooth throughflow through all modules. Since the lamella settler may permanently receive high loads of sludge, it was equipped by a mechanical cleaning mechanism. The inflow pump is stopped and the lamella modules are pivoting under water by a hydraulic drive to loosen up the sludge and to allow it to slide down. The manhole is then emptied to a sanitary sewer. For maintenance, it is possible to remove and re-insert the modules manually.

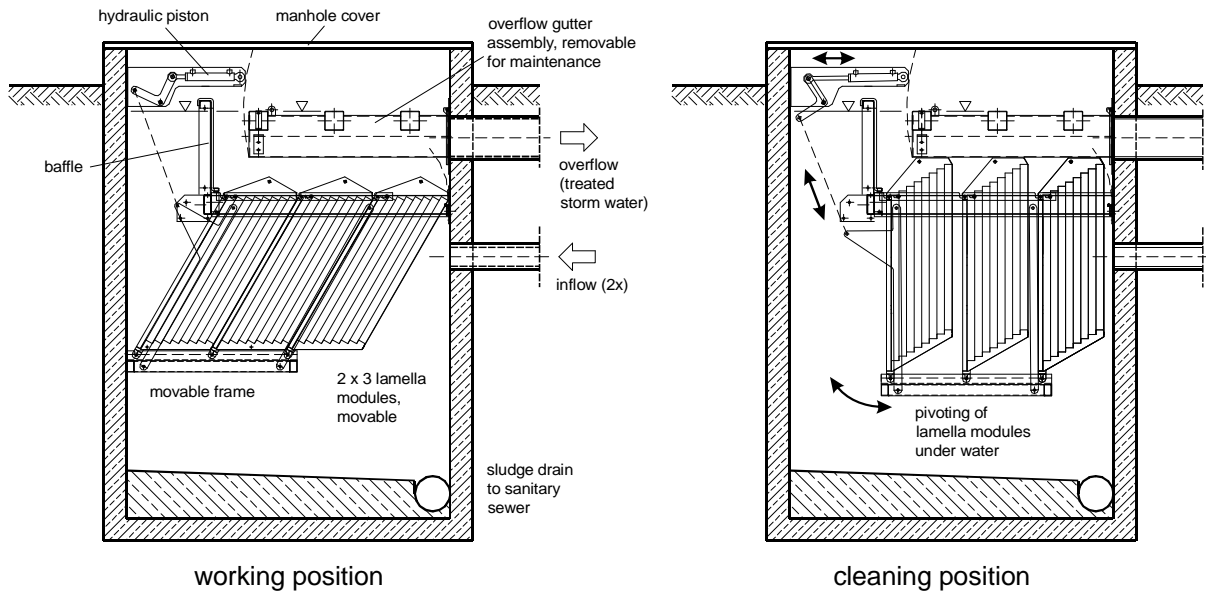


Fig. 8: For cleaning, the lamella modules are pivoting under water by a hydraulic drive. The sludge slides down and is drained to a sanitary sewer.



Fig. 9: Testing of the pivot mechanism (overflow gutters not yet installed)



Fig. 10: Unit ready for operation (the overflow pipes with drainholes have been replaced by now by open gutters which are less sensitive to clogging by tree leaves)

LIST OF REFERENCES

- Andritschke, N. (2010): Lamellenfilter zur Regenwasserreinigung. *wwt* 2/2010, S. 41-42
- ATV-A 128 (1992): Richtlinien für die Bemessung und Gestaltung von Regenentlastungen in Mischwasserkanälen. DWA-Arbeitsblatt.
- Boogaard, F.C., Langeveld, J.G., Liefing, H.J., Kluck, J. (2010): Stormwater quality and removal efficiency rates of lamella filters. NOVATECH 2010, Session 2.3
- Bridoux, G., Villeroux, A., Riotte, M., Huau, M. (1998): Optimisation d'un décanteur lamellaire au traitement des eaux pluviales. NOVATECH 1998, pp. 429-
- Brombach, H., Weiss, G., Pisano, W. (2008): Clarifier-type CSO tanks: Hydraulic design for optimum sedimentation efficiency. 11th International Conference on Urban Drainage ICUD, Edinburgh (Scotland)
- BWK-Merkblatt 3 (2001): Ableitung von immissionsorientierten Anforderungen an Misch- und Niederschlagswasserleitungen unter Berücksichtigung örtlicher Verhältnisse. Düsseldorf: Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (BWK) e.V.
- DWA-A 166 (2010): Bauwerke der zentralen Regenwasserbehandlung und -rückhaltung: Konstruktive Gestaltung und Ausrüstung, Entwurf. DWA-Arbeitsblatt.
- DWA-M 153 (2007): Handlungsempfehlungen zum Umgang mit Regenwasser. DWA-Merkblatt.
- Fuchs, S., Brombach, H., Weiß, G. (2004): New database on urban runoff pollution. NOVATECH 2004, Vol. I, pp. 145-152
- Fuchs, S., Mayer, I., Haller, B., Roth, H. (2010): Einsatz von Schrägklärern in der Regenwasserbehandlung. *KA Korrespondenz Abwasser, Abfall* 57. Jhg., Heft 11, S. 1109-1117
- LfUBW (1997): Wirbelabscheideranlagen: Hinweise zu Entwurf und Bemessung. *Handbuch Wasser* 4, Band 5. Karlsruhe: Landesanstalt für Umwelt Baden-Württemberg
- LfUBW (2008): Technische Regeln zur Ableitung und Behandlung von Straßenoberflächenwasser. Karlsruhe: Landesanstalt für Umwelt Baden-Württemberg
- Schade, H., Sapulak, A. (1984): Parallelplattenabscheider (Tilted Plate Settler). *Korrespondenz Abwasser*, No. 2, pp. 104-111
- Schmitt, Th. (2012): Weiterentwicklung des DWA-Regelwerks für Regenwetterabflüsse. Ein Werkstattbericht. *KA Korrespondenz Abwasser, Abfall*, 59. Jhg., Heft 3, S. 192-200.
- Schaffner, J., Pfeffermann, A., Eckhardt, H., Steinhardt, J. (2010): Inflow based investigations on the efficiency of a lamella particle separator for the treatment of stormwater runoffs. NOVATECH 2010, Session 2.3.
- Takayanagi, E., Abe, T., Taruya, T., Fukui, S. (1996): Introduction of plate settler for combined sewer overflow treatment. 7th International Conference on Urban Storm Drainage ICUSD, Hannover (Germany), pp. 893-898
- Vasquez, J., Morin, A., Dufresne, M., Wertel, J. (2010): Optimisation de la forme des décanteurs lamellaires par la modélisation hydrodynamique 3D. NOVATECH 2010, Session 2.3.
- WHG (2010): Gesetz zur Ordnung des Wasserhaushalts (Wasserhaushaltsgesetz). *Bundesgesetzblatt* 2009 Teil I Nr. 51, ausgegeben am 6. August 2009, S. 2585. In Kraft seit 1. März 2010.