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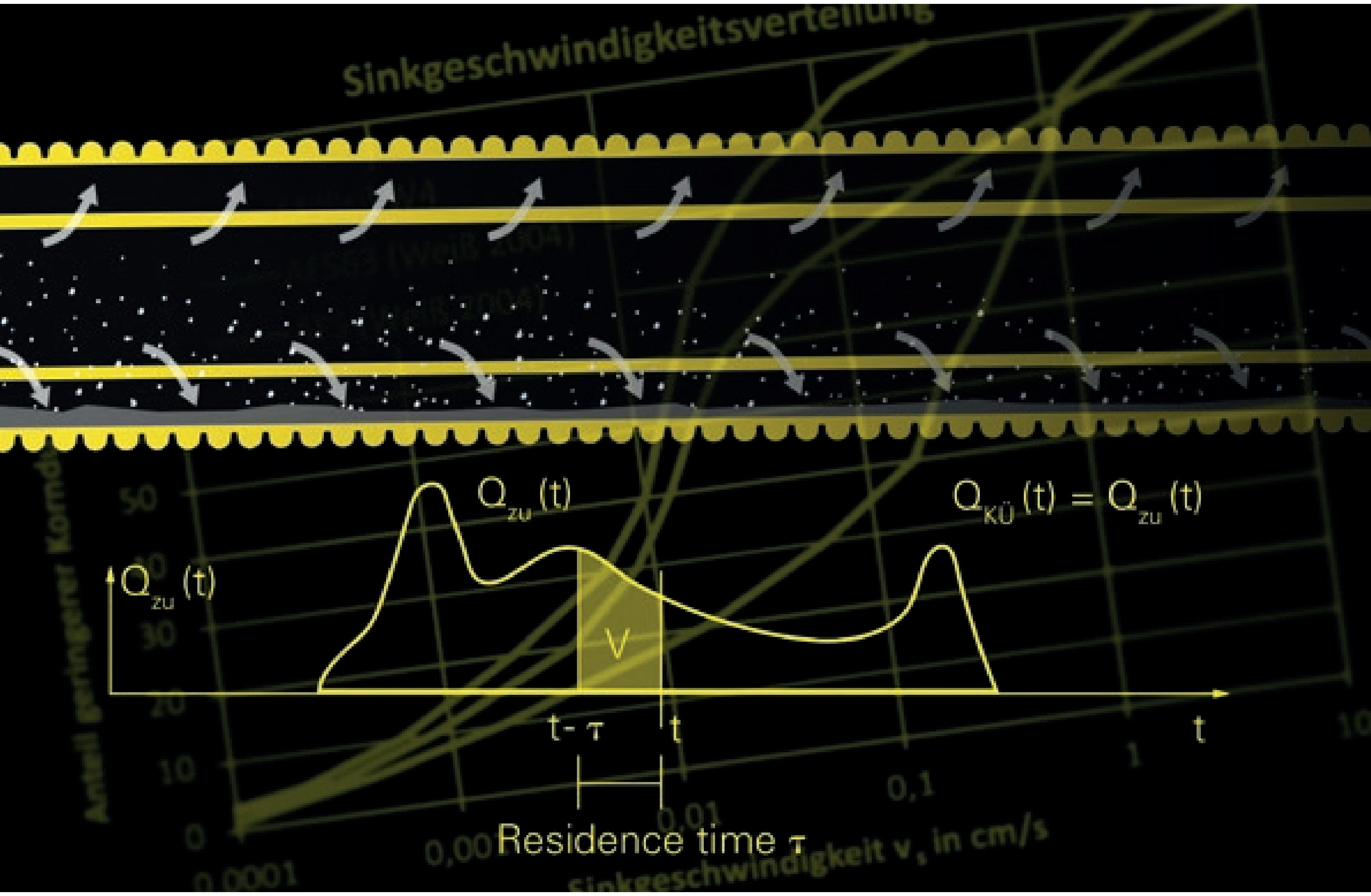
Technical information

SediPipe – Residence time method



Verification procedure for SediPipe tubular sedimentation systems based on residence time (compliant with DWA-A 102-2/BWK-A 3-2 – Chapter 6.1.3.4. special forms)

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1 General information

Section 6.1.3.4 of the DWA-A 102-2/BWK-A 3-2 regulations “Principles for the Management and Treatment of Stormwater Runoff for Discharge into Surface Waterbodies – Part 2: Emission-related Evaluations and Regulations” (*Grundsätze zur Bewirtschaftung und Behandlung von Regenwetterabflüssen zur Einleitung in Oberflächengewässer – Teil 2: Emissionsbezogene Bewertungenund Regelungen*) describes special forms of structures or factory-made technical systems for stormwater treatment. These must meet the relevant requirements regarding substance retention and continuous operation. The evaluation of effectiveness of these special form systems shall take place on a case-by-case basis as part of a verification procedure (Section 8, DWA-A 102-2/BWK-A 3-2).

Factory-made SediPipe sedimentation systems fall within the definition of the above-mentioned special forms. The proven product line by FRÄNKISCHE consists of stretched, compact pipes with a permanent water level and longitudinal flow serving as sedimentation reactors, which additionally feature a specifically developed flow separator that reliably prevents remobilisation of the sediment depot even during massive inflows (Fig. 1).

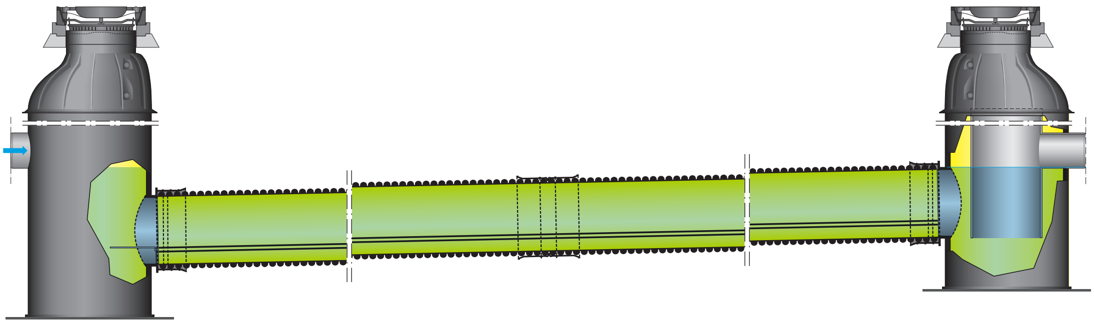


Fig. 1: Example representation (longitudinal section) of a SediPipe XL system

The specifically developed and technically recognised verification procedure – **"residence time method"** – is described in the following.

It has been developed in direct cooperation with Dr.-Ing. Gebhard Weiß of UFT (Umwelt- und Fluid- Technik Dr. H. Brombach GmbH).

2 Description of the residence time method

Conventional stormwater sedimentation tanks for the treatment of stormwater runoff from separate sewer systems and subsequent discharge into surface waterbodies are to be operated without permanent water level in the future (acc. to Section 6.1.3.2, DWA-A 102-2). In the past, they were classified according to DWA-M 153 (2012) and dimensioned according to DWA-A 166 with regard to a permissible flow rate q_A with a critical rain yield factor r_{crit}.

The DWA-A 102-2/BWK-A 3-2 worksheet published in December 2020 adopts a different approach with the utilisation of an area-specific AFS63 filterable dirt removal in kg/(ha·a) and a permissible area-specific dirt discharge into waterbodies.

Evidence of sufficient efficiency and therefore of a corresponding separation effect must now be provided for treatment systems.

In order to be able to describe the variable stormwater inflows occurring in practise and the related, temporarily unsteady sedimentation processes, a system-specific verification procedure has been developed which is called the "residence time method".

The procedure calculates the residence time $\tau(t)$ of the water currently discharged from the treatment system at any point in time t. This shows the realistic residence time of stormwater in the system as well as the related sedimentation processes. By using the residence time $\tau(t)$ instead of the flow rate q_A, the unsteady flow and sedimentation process is described without the assumption of a quasi-stationary flow as necessary for the usual sedimentation formulae (efficiency = $f(q_A)$). A sedimentation routine that depends on the residence time allows for long-term simulation and, eventually, the calculation of substance discharge.

Thus, the effect of sedimentation over extended time can also be considered in cases when the reactor has no water flow but does have a permanent water level (batch effect). The water escaping directly after this time period has had a long residence time, and has therefore only a low fine AFS63 solids concentration.

This effect has a significant positive impact on the overall efficiency η_{tot} especially in systems such as SediPipe, which are constructed and designed accordingly. However, it can be shown that very long residence times are the exception, also due to the low, specific storage volume of SediPipe as compared to stormwater sedimentation tanks. In connection with the always constant displacement flow (Fig. 2), relevant impact shocks of waterbodies from long-term resolution processes or chloride stratification can thus be excluded.

Fig. 2: Theoretic representation of the plug flow (displacement flow) in the sedimentation pipe

This has been proven by means of various effectively measured as well as synthetic Niedsim rain series by the LUBW (*Landesanstalt für Umwelt Baden-Württemberg*). Figure 3 shows that 67–88 % of the overflow volume have a residence time of less than 24 hours. In contrast, only 3–8 % show a residence time of more than one week.

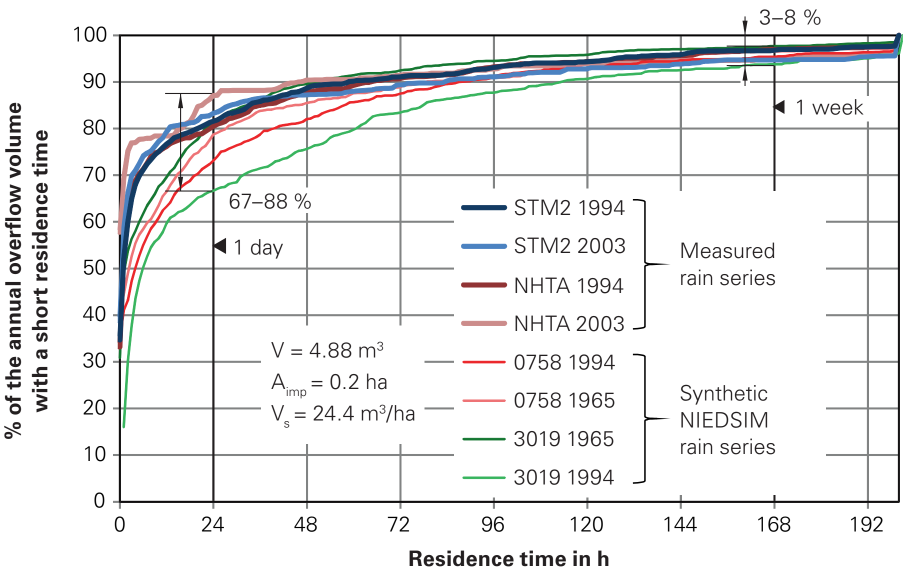


Fig. 3: Percentage of the overflow volume as a function of the residence time for some 1-year rainfall series

3 Characteristics of the calculation model

The model combines the volume simulation of a commercial pollution load model with long-term simulation (e.g., KOSIM) with an external sedimentation routine for describing different reactor sizes and operating modes. A parallel plug flow (displacement flow), which has been proven in several model and large-scale experiments, is simulated in the stretched, compact SediPipe sedimentation reactor (Fig. 2).

The water entering the system is continuously "fed through" depending on the inflow (Fig. 4 and 5).

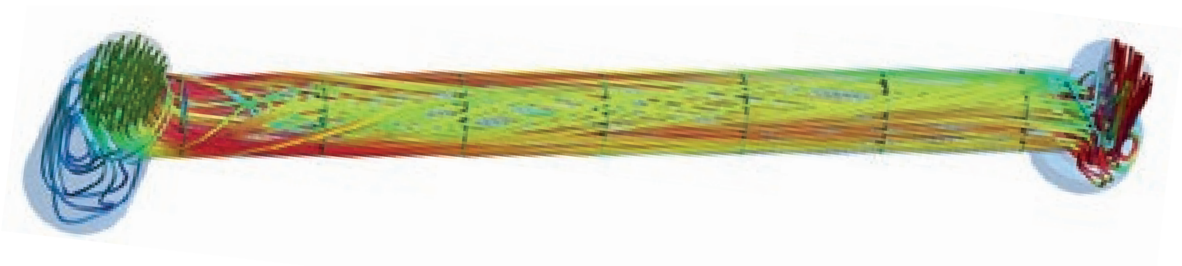


Fig. 4: Representation from CFD simulation

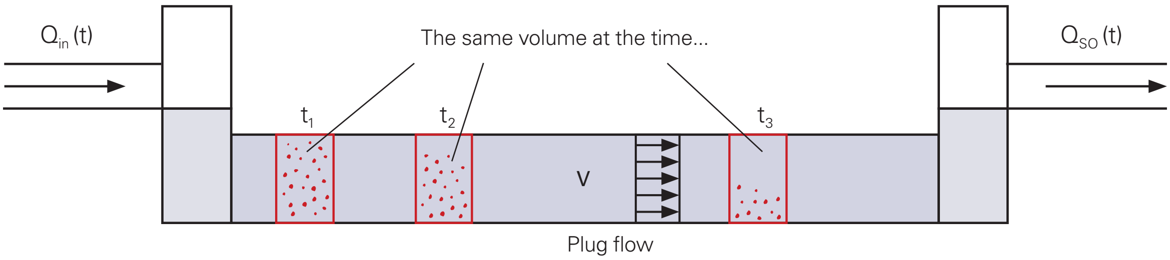


Fig. 5: Model representation of a plug flow (displacement flow) with a superimposed sedimentation process in a stretched, compact sedimentation pipe with permanent water level

The residence time τ(t) calculated describes the period of time spent in the sedimentation pipe by the water overflowing at the time t. Suspended solids (*absetzbare Feststoffe – AFS*) are able to sediment during this time. The sedimentation routine used is a modified approach according to Fair-Geyer (1954), in which the residence time has been introduced instead of the flow rate; see Weiß and Schütz (2017).

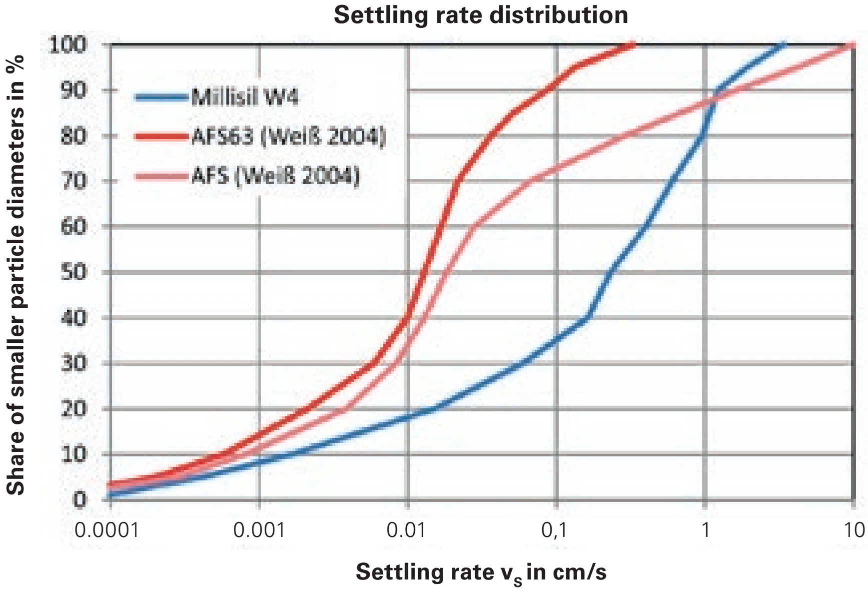
Eventually, an integration over the total time provides the relief volumes, the area-specific AFS63 load discharge in kg/(ha·a), and the overall efficiency η_{tot} of the relevant SediPipe system.

In addition to this, an assumption about a typical settling rate distribution of the AFS63 particle size fractions has been made as in Weiß (2014) (Fig. 6).

The AFS total curve (pink line) is based on several examinations of suspended particles from separate sewer systems from the literature which, including the very fine fractions, result in very low medium settling rates. This becomes apparent in the direct comparison with the settling rate curve of Millisil W4 (blue line).

For the relevant AFS63 curve (red line), the coarse fractions (> 63 µm) with high settling rates are analytically separated, starting with the AFS total curve, and the curve is re-calculated accordingly.

The resulting AFS63 curve (very fine fractioning) shows very low settling rates. Real sewer sediment (mud) shows, beyond the AFS63 share, also larger shares of coarser, more easily settleable materials that are easily settleable in SediPipe systems.



Supporting weights of the curves			Fractioning		AFS63	AFS
	AFS	AFS63	Fraction	Percentage share	Medium settling rate	Medium settling rate
Vol.-%	vs in cm/s	vs in cm/s		ai in %	vs in cm/s	vs in cm/s
100	10,00000	0,33000	95-100	5	0,23168	7,10848
95	4,21697	0,13335	90-95	5	0,10997	2,92407
90	1,63117	0,08660	80-90	10	0,06156	0,96062
85	0,68786	0,05158	70-80	10	0,02913	0,17845
80	0,29007	0,03652	60-70	10	0,01927	0,04751
70	0,06683	0,02175	50-60	10	0,01487	0,02324
60	0,02818	0,01679	40-50	10	0,01148	0,01563
50	0,01830	0,01296	30-40	10	0,00798	0,01069
40	0,01296	0,01000	20-30	10	0,00404	0,00614
30	0,00841	0,00596	10-20	10	0,00135	0,00234
20	0,00387	0,00211	5-10	5	0,00039	0,00055
10	0,00082	0,00058	0-5	5	0,00012	0,00016
5	0,00029	0,00021				
0	0,00003	0,00003				

Fig. 6: Distribution curves of settling rates of the model sediments used as well as calculation curves for AFS and AFS63 (source: UFT wiki)

4 Validation of the calculation model

The calculation model has been validated and substantiated by means of numerous model and large-scale as well as in-situ examinations with a constant as well as time-variable flow.

Figure 7 gives an example of a recorded rainfall event (solid lines) for a SediPipe system in Münster (Leutnant et al. 2018) and shows relevant discharge and concentration hydrographs (dashed lines) generated by the calculation model.

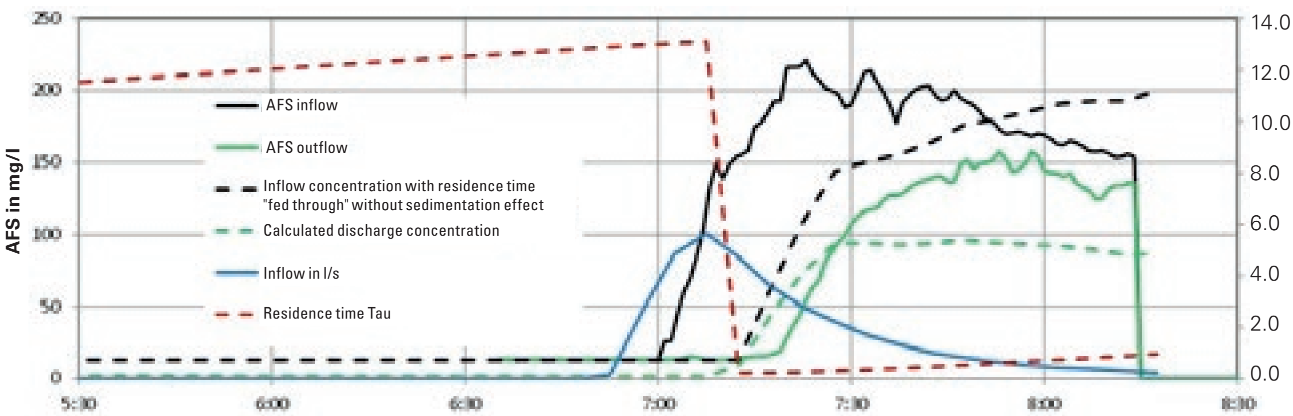


Fig. 7: Qualitative substantiation of the calculation model by means of the recorded discharge and concentration hydrographs

The following results can be determined:

- Qualitatively correct representation of the residence time (red dashed line) and the inflow concentration arriving at the outlet with the residence time delay (black dashed line)
- Qualitatively correct representation of the sedimentation in the system depending on the residence time (green dashed line), comparison with the concentration measured at the outlet (green line)

The continuous optimisation of the calculation model described (long-term simulation) will be effected by means of results of ongoing in-situ examinations also in the future. The interpretation of the results is supported by the expertise of external professional competences.

5 Dimensioning procedure

As a basis for the dimensioning procedure for SediPipe sedimentation systems, the calculation model is used to perform several simulation runs to determine the dependency between the area-specific load discharge and different input parameters (connected area, availability of a tank overflow, etc.). This results in corresponding diagrams for the individual SediPipe system types (Fig. 8-11). In accordance with the DWA-A 102-2/BWK-A 3-2 criteria, the maximum connectable paved area $A_{p,c}$ can be derived from these diagrams with regard to the area-specific substance discharge AFS63 of the relevant area $b_{R,a,AFS63}$.

A rain series that is assumed to be generally applicable to all sites has been used to create the dimensioning diagrams. This is a 46-year rain series (01.01.1961–31.12.2006) at the Mühldorf am Inn station. This is the same station from which the stormwater runoff yield factors were taken for the DIBt test method for decentralised stormwater treatment systems (Schmitt et al. 2010).

Hence, a generally applicable dimensioning procedure was developed on the basis of the verification procedure as a long-term simulation according to Section 8 DWA-A 102-2/BWK-A 3-2. This validated and substantiated simulation model, which has already been published and recognised in professional circles, can also be used to perform a project-specific simulation with a long-time local rain series.

This makes it possible to simulate the efficiency of several SediPipe sedimentation systems in connection with the existing drainage system (cascading, series connection of systems) as well. Therefore, also specific, local conditions can be considered, if needed.

The data from the above-mentioned dimensioning procedure are the basis for a specifically developed calculation tool by FRÄNKISCHE (RigoPlan dimensioning module DWA-A102-2/-BWK-A 3-2 Version 1.0), which allows for simple and intuitive dimensioning of SediPipe stormwater treatment systems relative to the object-specific input data according to DWA-A 102-2/BWK-A 3-2 (area sizes $A_{p,c,i}$, area categories, etc.).

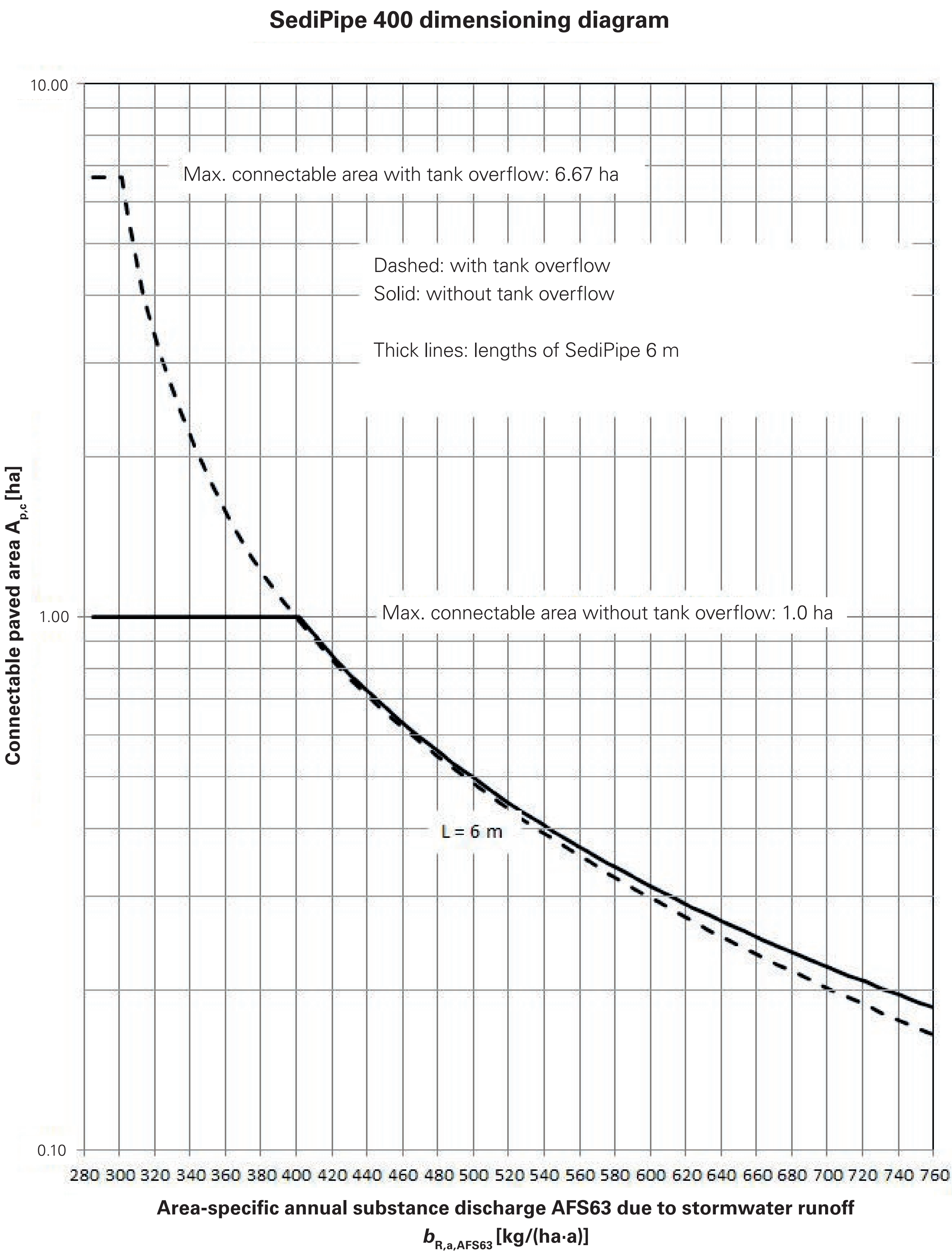


Fig. 8: SediPipe 400 dimensioning diagram

SediPipe 500 dimensioning diagram

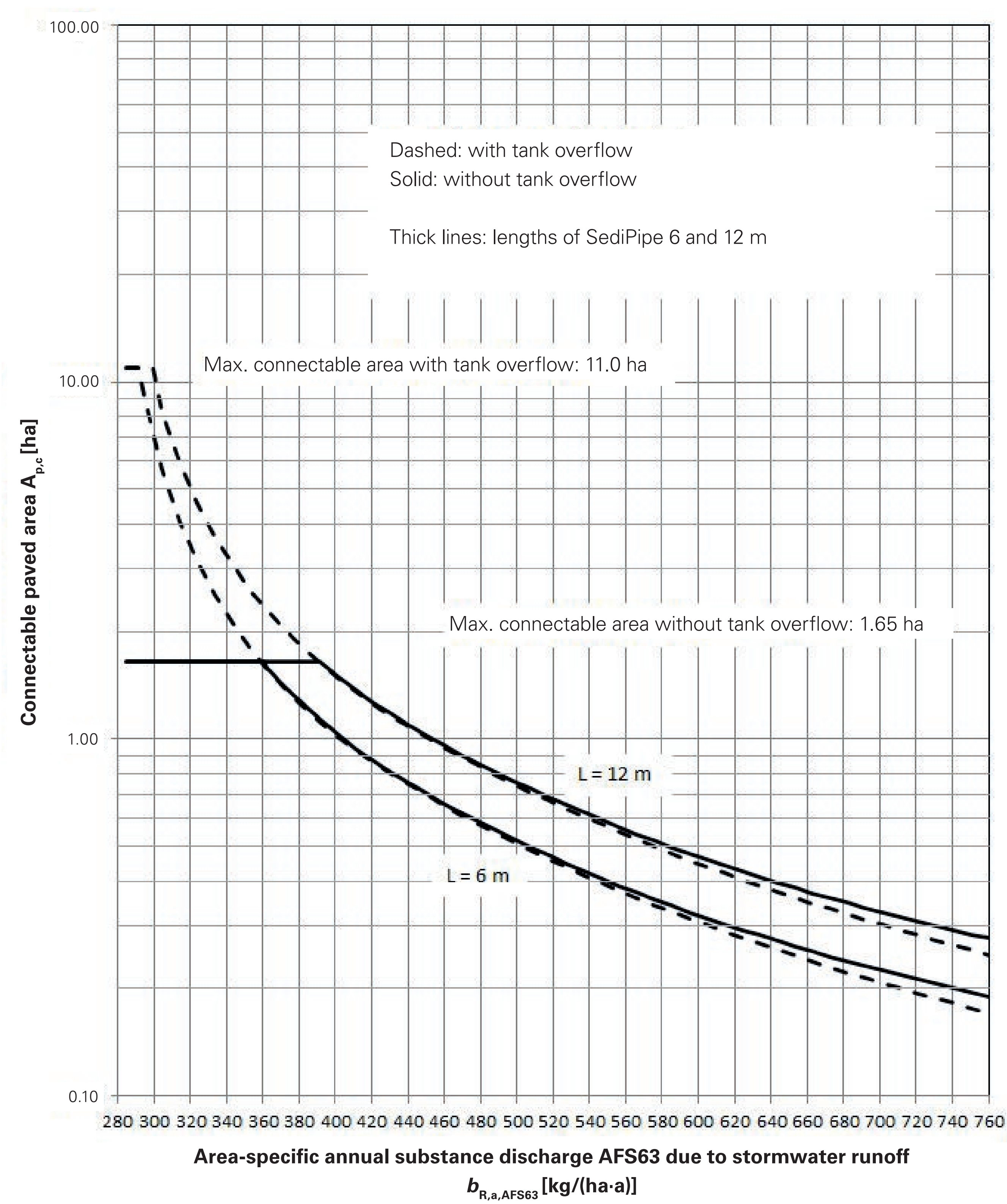


Fig. 9: SediPipe 500 dimensioning diagram

SediPipe 600 dimensioning diagram

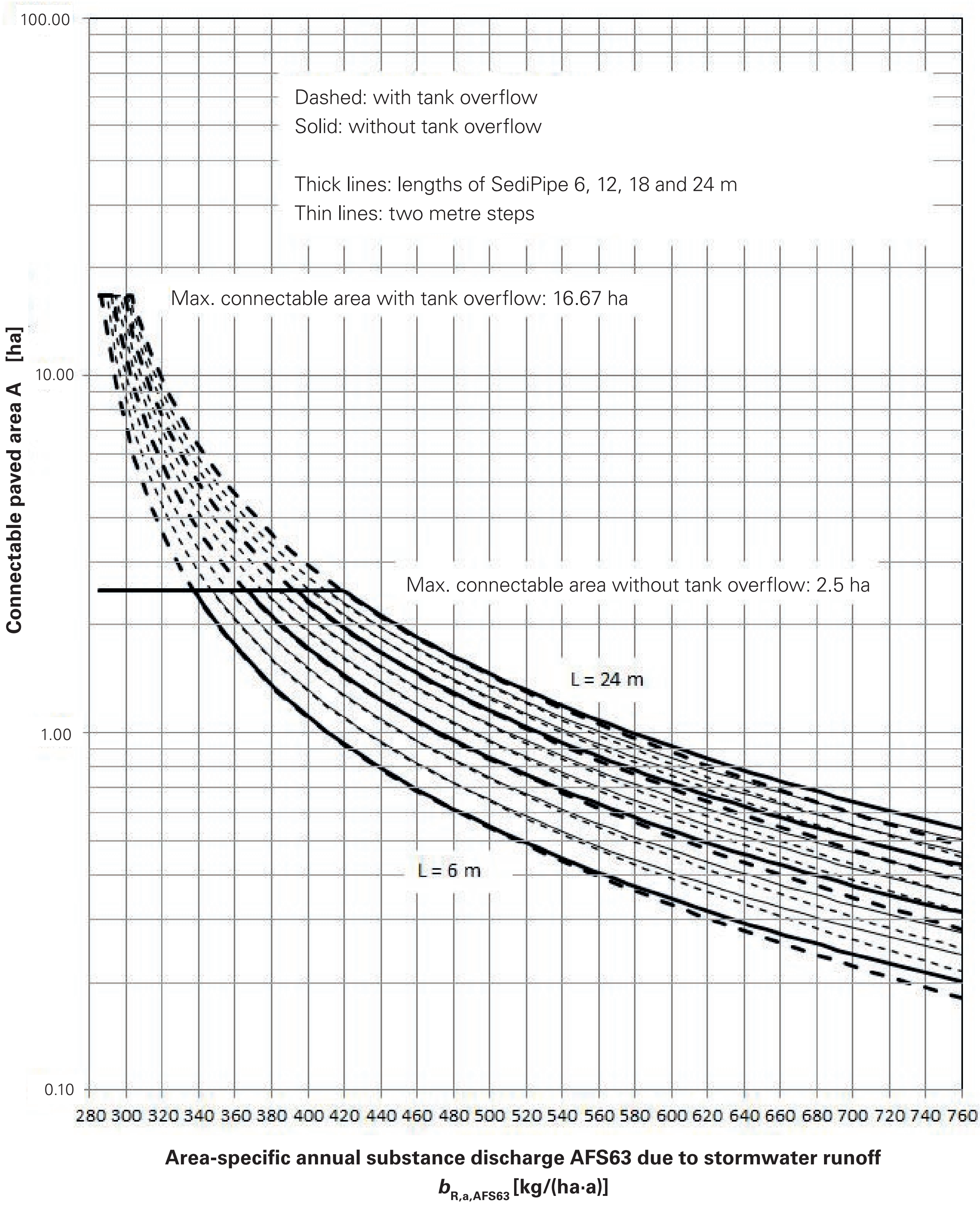


Fig. 10: SediPipe 600 dimensioning diagram

Example: With 530 kg/(ha·a) AFS63 surface removal, some 0.45 ha of paved area can be connected to a 6-metre SediPipe system without tank overflow, without exceeding the load discharge of 280 kg/(ha·a) permissible according to DWA-A 102-2.

SediPipe 800 dimensioning diagram

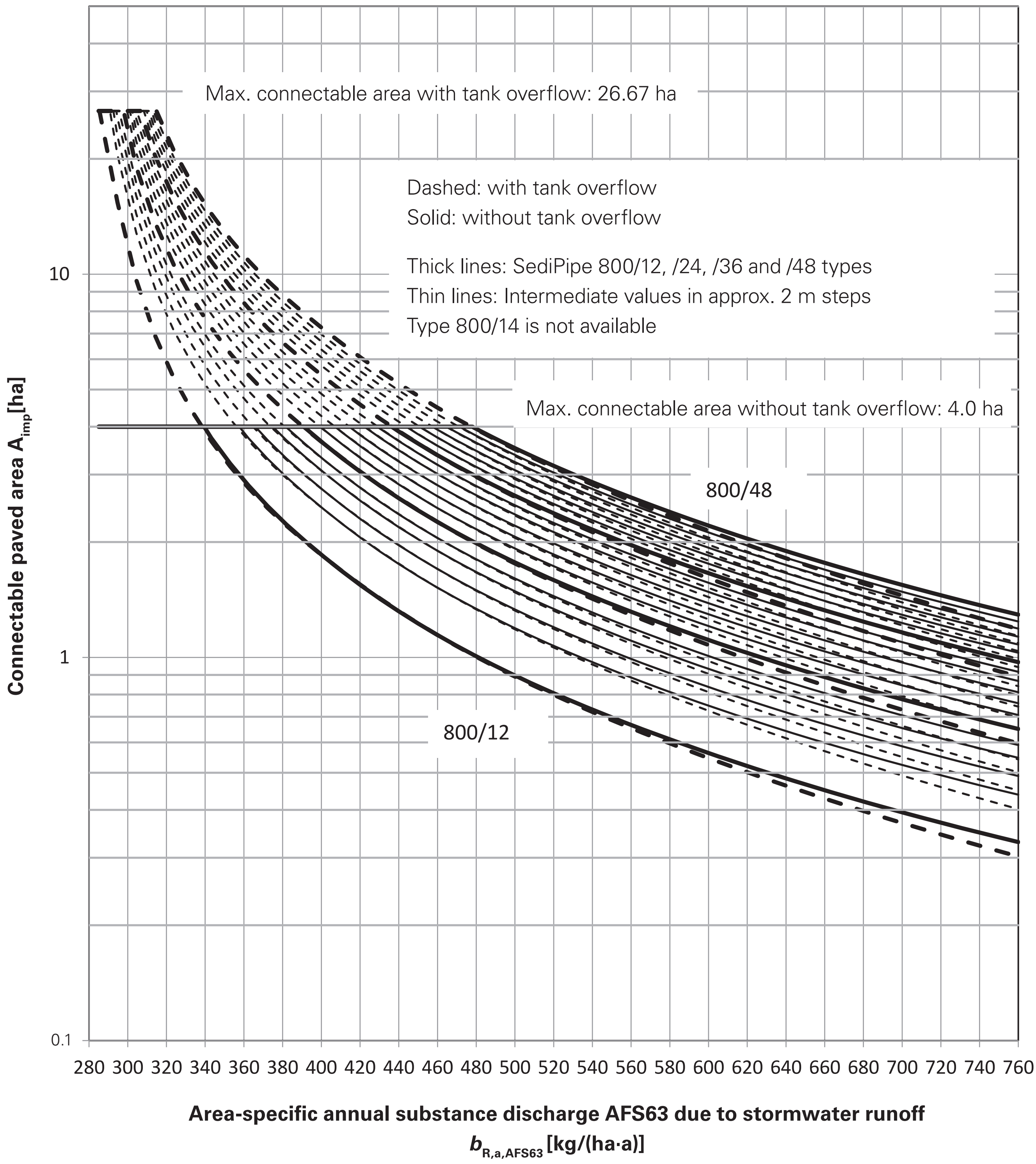


Fig. 11: SediPipe 800 dimensioning diagram

6 Summary

Modelling the sedimentation process in tubular, stretched, compact SediPipe sedimentation systems by means of the residence time helps to avoid deficiencies of conventional approaches on the basis of the flow rate.

It is possible to prove that in systems of this type with a permanent water level, which additionally have only a small area-specific volume, only minor shares of the water that escapes from these systems into the waterbodies every year have long residence times.

In connection with the always constant displacement flow, relevant impact shocks of waterbodies from long-term resolution processes or chloride stratification can thus be excluded.

On the basis of the calculation model, DWA-A 102-2/BWK-A 3-2-compliant dimensioning diagrams have been created for various sizes and operating modes of SediPipe sedimentation systems.

7 Literature

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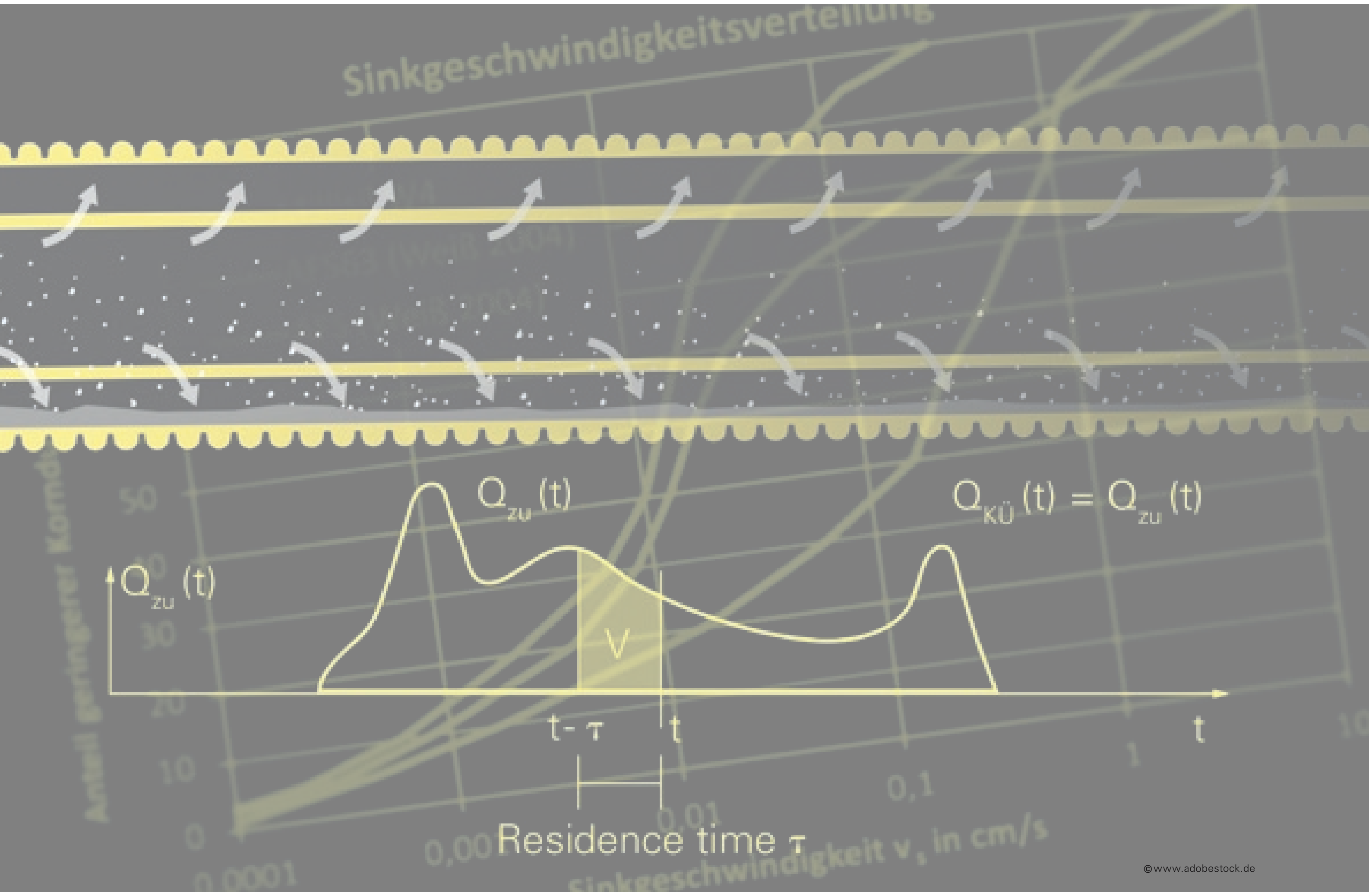
Notes



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