Selection of a reference material for the testing of decentralized stormwater treatment facilities

Sélection d´un outil de référence pour l'évaluation des ouvrages de traitement des eaux pluviales décentralisés

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RÉSUMÉ

Les ruissellements d'eau de pluie des toitures et des zones de trafic (routes et parcs de stationnement), peuvent polluer les eaux réceptrices. Il est donc nécessaire de traiter certains ruissellements avant qu'ils n'atteignent les eaux réceptrices. Il est possible d'utiliser des installations de traitement décentralisées standardisées comme alternative aux dispositifs classiques en fin de processus. L'utilisation globale de ces installations nécessite une évaluation systématique des systèmes au regard de leur rendement avec une procédure d'essai standardisée.

La vérification de l'élimination de la plus grande partie des particules d'hydrocarbures aromatiques polycycliques (HAP) et des métaux lourds doit être effectuée à l'aide du paramètre alternatif des solides totaux en suspension (STS). Au stade actuel, on ne sait pas avec précision quelle partie des polluants est sorbée dans la fraction fine des poussières de rues.

Après étude de la littérature et évaluation de données, la fraction granulométrique pertinente pour les ruissellements de voies et les installations décentralisées de traitement des eaux de pluie a été déterminée. Ensuite, la distribution des HAP et des métaux lourds dans les différentes fractions granulométriques a été étudiée. Les résultats conduisent à un matériau d'essai de référence qui peut représenter la pollution des ruissellements d'eaux de pluie provenant de zones de trafic.

ABSTRACT

Stormwater runoff from roofs and trafficked areas like roads and car parks can impair receiving waters by pollutants. Therefore runoffs from some area types have to be treated prior discharge to receiving waters. Standardized, decentralized treatment facilities can be used as an alternative to conventional end of the pipe devices. The overall use of those facilities requires a systematically evaluation of systems with regard to their efficiency with a standardized testing procedure.

The verification of the removal of mostly particulate polycyclic aromatic hydrocarbons and heavy metals should be carried out with the help of an alternative parameter « total suspended solids » (TSS). So far, it is not clear which part of the pollutants is sorbed at the fine fraction of the street dust and dirt.

With the help of a literature study and an evaluation of given data it was investigated, which particle size fraction is relevant for street runoffs and decentralized stormwater treatment facilities. Secondly, it was investigated, how PAH´s and heavy metals are distributed within different particle size fractions. The results lead to a reference testing material that can realistically represent the pollution of stormwater runoff from trafficked areas.

KEYWORDS

Testing methods, storm water treatment, street runoff, suspended solids, particulate harmful substances, size distribution

1 INTRODUCTION / MOTIVATION

Every day the total paved area in Germany increases about 100 hectares, while the total number of inhabitants stagnates or decreases [Werner, 2006]. Buildings and impermeable surfaces and the loss of vegetation lead to a significant reduction of evaporation and implements changes of the soil-water household and the natural recharge of aquifers. Surface runoffs from these areas may contain pollutants and have negative effects on receiving water organisms [Gaskell et al. 2009]. Therefore potential pollutant emissions from those areas must be reduced under certain conditions. This can be achieved by using standardized, decentralized stormwater treatment facilities instead of the traditional end of the pipe solutions. The overall use of those facilities needs a systematic assessment of the efficiency and the longevity of these systems in a standardized evaluation protocol.

In the introduced testing procedure for the assessment of systems that treat street runoff, the removal of total suspended solids (TSS) was chosen as a decisive parameter. The evaluation shall use a reference material with a standardized particle size distribution. The reason for using a solid material is that polycyclic aromatic hydrocarbons (PAH) and many heavy metals can be found mainly in a particulate form in the runoff. By using solids as a substitute for pollutants, the test procedure leads to minor costs and decreasing environmental pollution in comparison to the operation with single pollutants.

For the definition of demanded efficiency the following procedure was chosen. The relation between average PAH-concentration in street runoff (calculated from a literature survey) and the permissible limit for discharge of seepage into soil/groundwater of the German soil restoration law [BBodSchG 1998] leads to an efficiency that must be reached by the treatment facilities. In the case of infiltration of street runoff this value is 92 %.

Open questions still remain concerning the aspect, which proportion of PAH and particulate heavy metals in the fine solid fraction of the road dust and the street runoff should be considered by a synthetic testing material. If too coarse particles are used, the part of PAH and particulate heavy metals would not fit in the behaviour of a real street runoff. If a material in the testing procedure is too fine the test might be too strict.

Therefore the following questions were investigated in the paper considering a literature study and an evaluation of existing data:

1. Which particle size fraction is relevant in street runoff and is transported into stormwater treatment facilities?
2. How does the fractioning of PAH´s and selected heavy metals looks like?
3. Which is the optimal particle size distribution for a standardized testing material that represents the particles in a real runoff?

2 RUNOFF RELEVANT PARTICLE SIZE

In Figure 1 the particle size distribution curves of road dust and dirt from different investigations from Australia, the United States and Europe is presented. One main result is, that the distributions between the countries are extremely heterogeneous. While in Australia the fraction up to 150 µm is dominating, the distribution in US and Europe reaches up to 3,000 µm. The investigations in Australia mainly consist of sampled road runoff, while the US and European data mainly represents road dust and dirt. Therefore it has to be clarified which parameters influence the particle size distribution in road runoff and road dust and dirt and which are the differences concerning the particle size distribution.

Amount and contribution of street dirt and dust is influenced by different parameters. Sources of pollutants in runoff are traffic emissions (road abrasion, abrasion of tyres, combustion, drip losses etc) and excrement deposits on the road surface. The local vegetation also contributes potential contaminations in street runoffs. Furthermore, the land use in the catchment (commercial, industrial, private housing) also influences the solid load in street runoff.

Beneath input pathways also removal pathway are relevant. For example atmospheric turbulences originating in traffic activities, wind drift and road sweeping can lead to a reduction of pollutant potential on the street areas. When street runoff occurs, also each rain event changes the amount of pollutants by removing a part of the solids in dependence of the rain intensity. An additional removal of pollutants occurs in gullypots.

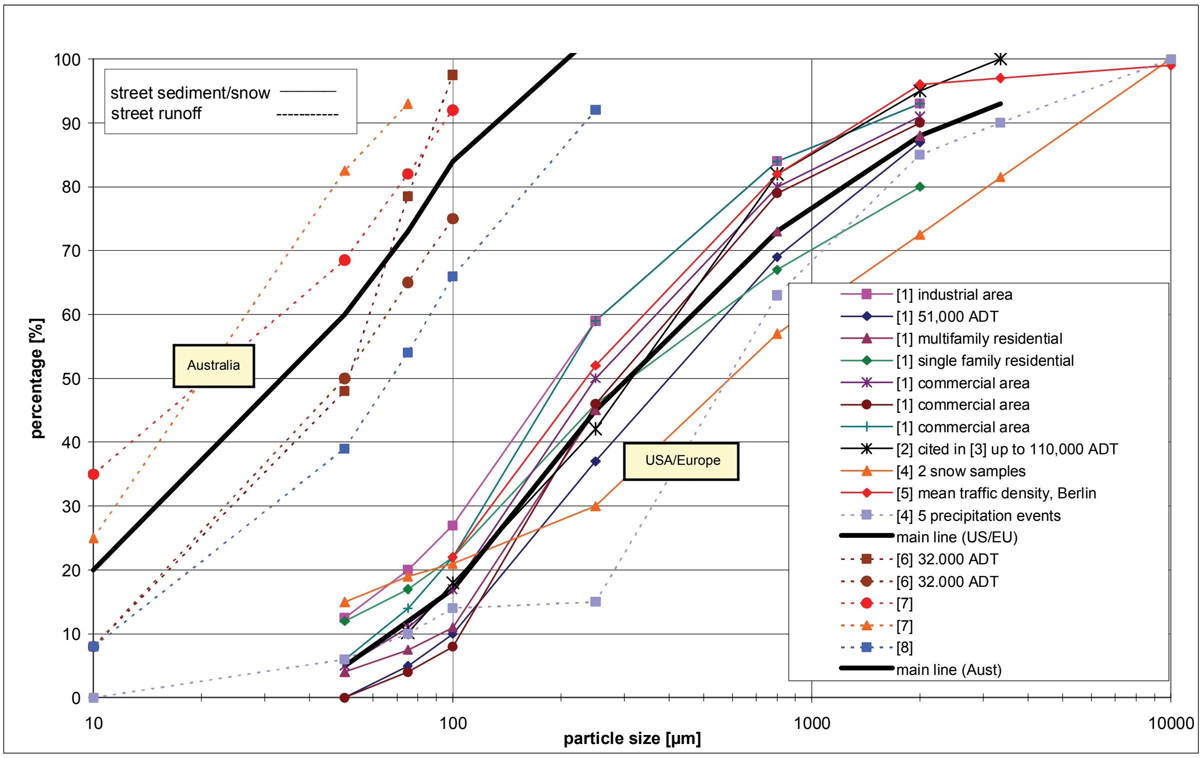

Figure 1. Particle size distribution curves of dust and dirt and solids in runoff from Australia, the United States of America and Europe. Sources: [1] Lau und Stenstrom, 2005; [2] Shaheen, 1975 (cited in [3]); [3] Brunner, 1977; [4] Sansalone and Buchberger, 1996; [5] Sommer, 2007; [6] Lloyd and Wong, 1999; [7] Drapper, 1998; [8] Ball und Abustan, 1995 (cited in [7]); ADT: average daily traffic [vehicles/ day]

All these parameters influence the amount and contribution (e.g. particle size distributions) of solids in street runoff.

Therefore the pollutant loads in street runoff at the same catchment can differ significantly. In Figure 2 two possible scenarios are shown, which describe the main influencing factors

In the first scenario the pollutant load in runoff is relatively high when a long dry period occurs; sediment can accumulate, no street cleaning takes place, no wind is evident and the intensity of the rain is so high, that there is a first flush effect.

In the second scenario the dry period is short, there is intensive road cleaning and there are wind influences, so that a lot of road dirt is not transported or stays on the street surface. The remaining particles can be removed by a next rain event with a higher flow rate.

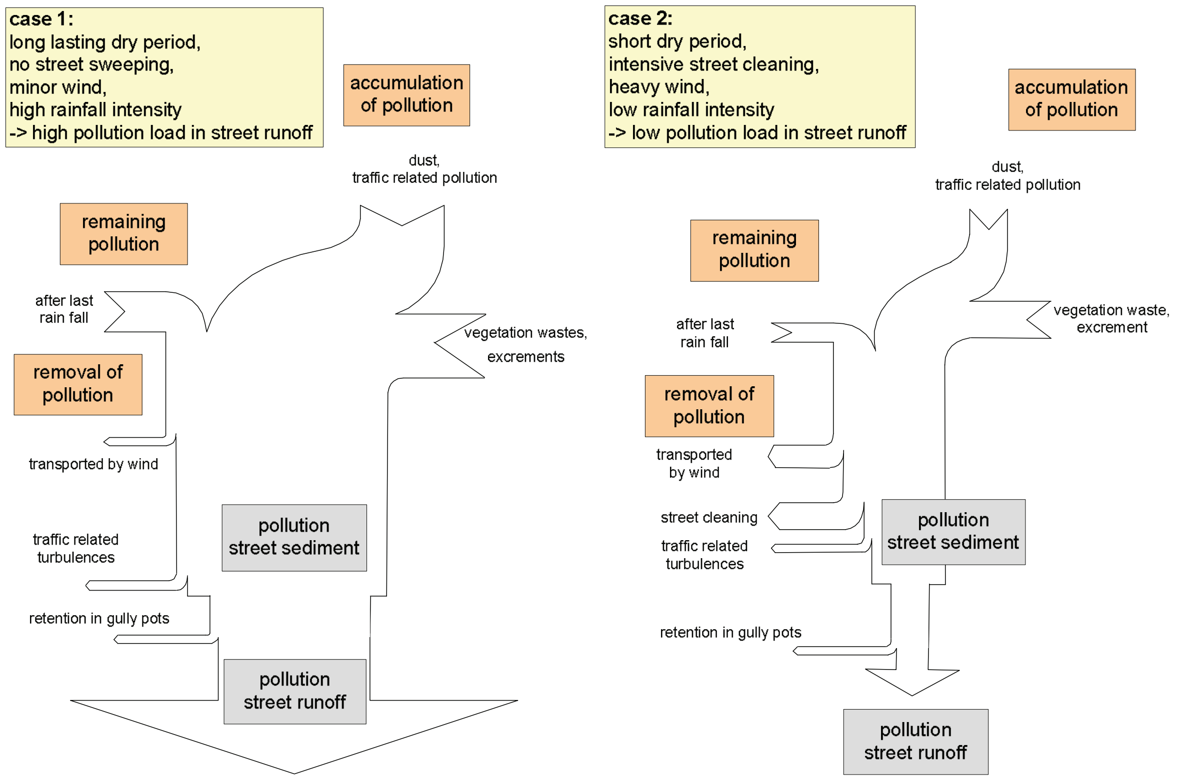

Figure 2. Loads of solids in road runoff in dependence of the boundary conditions

But how will those effects influence the particle size distribution of road dust and runoff? This is summarized Figure 3. On one hand the land use in the catchment influences the particle size distribution (emissions from traffic, industrial emissions and emissions from private housing (heating).

On the other hand the contribution of the surrounding surface material has a significant influence on the particle size distribution of the street dust or runoff. This can be an explanation for different particle size distributions of street dust and runoff in Australia and the US in Figure 1.

Additionally, the local vegetation also influences the particle size distribution in both directions. While leaves and branches belong to the coarse street dirt, pollen show very fine sizes mostly between 5 µm and 90 µm.

If wind and traffic caused turbulences are relevant, mainly fine solids will be swirled and transported. Therefore street dirt is possibly getting coarser by this effect.

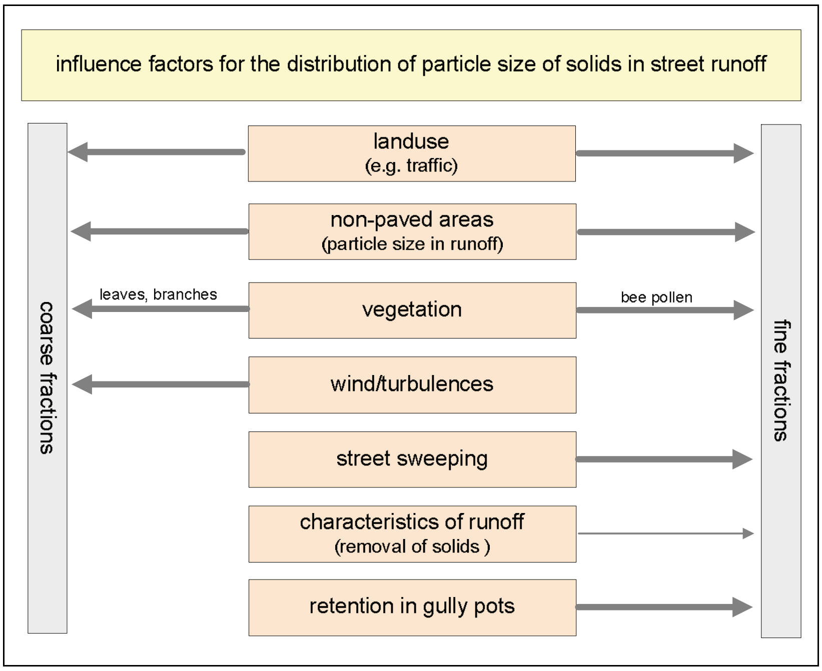

Figure 3. Influence of different boundary conditions on the particle size distribution in road runoff

Street sweeping leads to higher removal of the coarser fraction of the street dirt. In Table 1 the efficiencies of street sweepers concerning different particle size classes by one sweeping action is shown. The average efficiency for the total solids is about 50 %. Fractions coarser than 3.300 µm can be removed up to 95%. Fine particles up to 246 µm can be removed by 50 % and very small particles smaller than 43 µm are removed only by 15 %. [Brunner 1977, cited from Sartor and Boyd, 1972].

Table 1. Efficiency of road sweepers at the removal of different particle size fractions by one sweeping step [Brunner, 1977], cited from [Sartor and Boyd, 1972]

particle size [µm]e	removal rate [%]
> 3.300	95
2.000 bis 3.300	79
840 bis 2.000	66
246 bis 840	60
104 bis 246	48
43 bis 104	20
< 43	15

A further unknown factor is the removal by rain events. The following correlation exists:

- The finer the road dust is, the easier it will be removed from the surface.
- The higher the rain intensity is, the more road dirt (also coarser sediment) is flushed from the surface.

Therefore street runoff from rain events with lower intensities should have a smaller particle distribution curve; stronger rain events should contain coarser particles.

What are the differences between street dust and particles in street runoff? This is interesting because the data in the literature on one hand show particle distribution curves of street dust and on the other hand of particles in street runoff.

If a single rain event is intensive and no other removal effects take place (street sweeping) the total amount of solids with the complete size distribution are removed from the street. In this case data in street dust about size distribution and the adsorbed pollutants are comparable to date in street runoff.

All effects that would distinguish between size distribution results in street dust or street runoff are normally not known and furthermore extremely heterogeneous. Therefore in the following text there will be no differentiation between street dust and solids in corresponding runoff.

As already mentioned, reduction and change in the particle size distribution of solids in street runoff in comparison to street dust is generated by gully pots. The baskets in typical gully pots in Germany have screen apertures of 15 mm * 2 mm. By a secondary filter caused by leaves etc. in the baskets also smaller particles will be retained in those systems. Some gullies have silt traps where in dependence of the flow rates coarse solids can settle. The smaller the particles are, the lower is there sinking velocity.

Quartz particles with a density of 2.65 g/cm³ and a diameter of 200 µm for example have a sinking velocity of 3 cm/s; that means it needs 16 seconds until they reach the ground of a 50 cm deep silt trap. Solids with a density of 1.2 g/cm³ of the same particle size need nearly 1.5 minutes [Lange et al., 2003]. Most of the particles with a diameter smaller than 200 µm nearly totally come from the road runoff.

Therefore it can be assumed, that mostly particles up to 1.000 µm can be found after street sweeping and gully pots. Furthermore, the fraction up to 200 µm can nearly be totally found in the road runoff.

3 DISTRIBUTION OF HEAVY METALS TO GRAINSIZE DISTRIBTION CURVES

Suspended solids in stormwater runoff are an important transport media for pollutants like heavy metals and PAH´s. Therefore they have to be removed by stormwater treatment facilities. It is of special concern in which particle size fraction the majority of the pollutants can be found. Only with that knowledge the efficiency of treatment devices can be tested.

In Figure 4 the distribution of copper (representative for other heavy metals) is given from different investigation programs from the US and Europe. In the diagram an optical main line is given that summarizes all investigations.

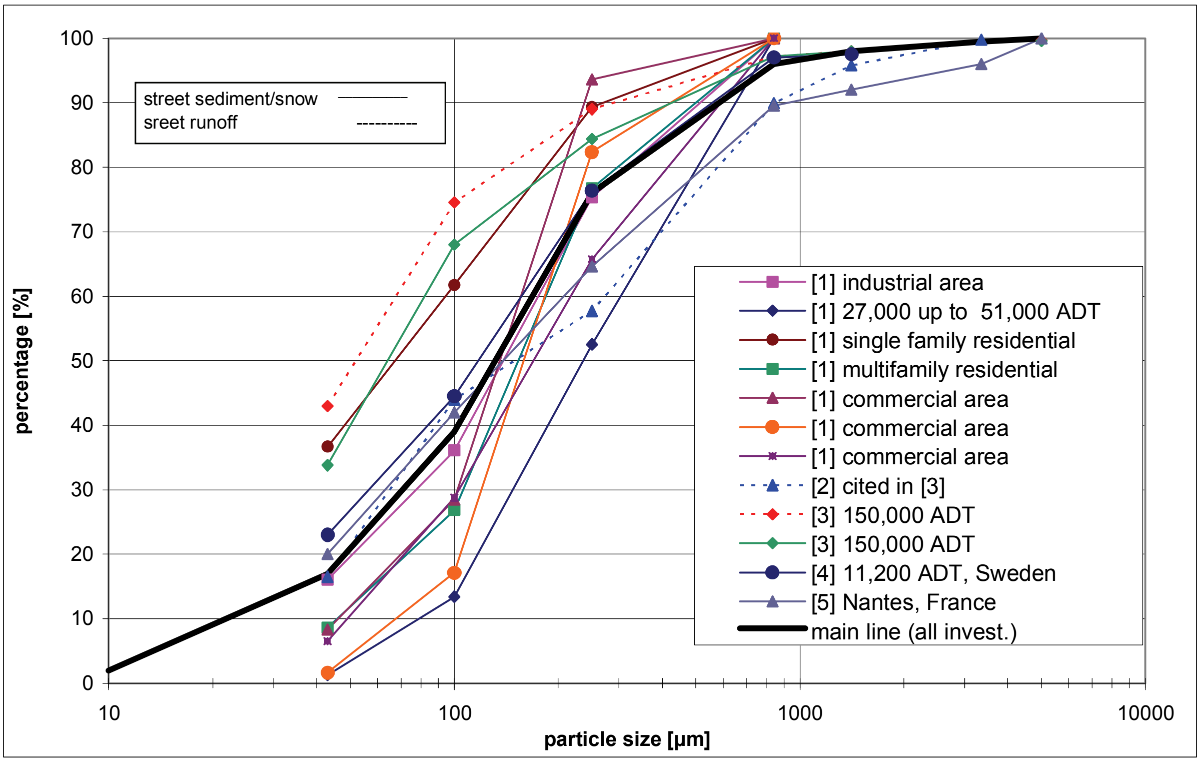

Figure 4.Copper attached to different particles sizes in road dust and road runoff. Sources: [1] Lau und Stenstrom, 2005; [2] Kobriger und Geinopolos, 1984 (cited in [3]); [3] Sansalone und Buchberger, 1996; [4] Germann und Svenson, 2000; [5] Colandini, 1997, ADT: average daily traffic [vehicles/ day]

It can clearly be seen that the particle size distribution of copper differs in comparison to the TSS. While particle size distributions of the TSS (values for USA and Europe) reach from 10 µm up to 5.000 µm, the particle size distribution of the heavy metals lays between 10 µm und 1.000 µm at a maximum of 3.000 µm. About 80% of the copper fraction is bound to particles with a diameter smaller than 200 µm. Therefore a testing material that represents copper in runoff must contain mostly particles with diameters smaller than 200 µm.

4 PARTICLE SIZE DISTRIBUTION OF PAH´S

In Figure 5 PAH-concentrations of different grain sizes from different investigation programs are given. The optical main line is displayed in black and bold. It is obvious that PAH show more than copper the affinity to attach to the fine fraction of the road dust. More than 80% of all the PAH are attached to the fraction of the road dust or road runoff smaller than 160 µm. One can see that the affinity of the PAHs to attach to the finest fraction in rural areas (Hunsrück, Germany) or in areas with small residential buildings is bigger than in industrial, commercial areas or areas with high traffic densities. It can be concluded that for representing PAH pollution a testing material must contain mainly particles smaller than 160 µm.

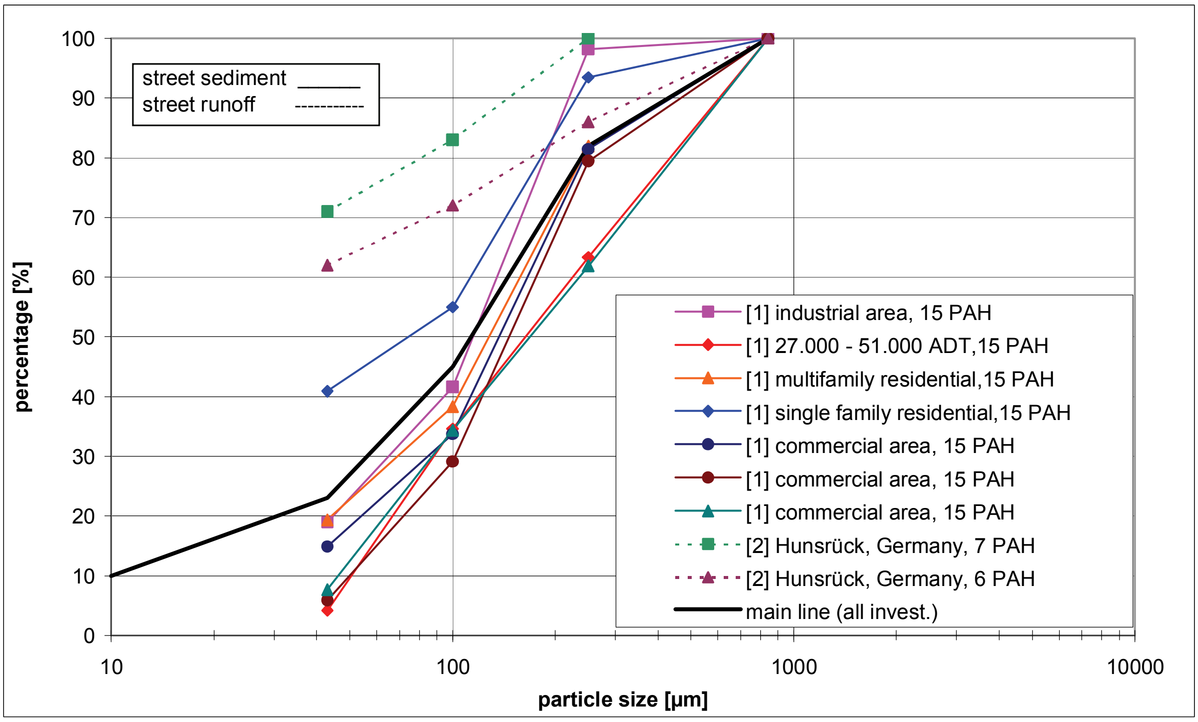

Figure 5. PAH attached to different particle sizes in road dust and road runoff. Sources: [1] Lau and Stenstrom, 2005; [2] Krein and Schorer, 2000; ADT: average daily traffic [vehicles/ day]

5 SELECTION OF A TESTING MATERIAL

A testing material that is used as a substitute for PAH and solid heavy metals must be always available on the market in a reproducible and equal grainsize distribution curve. The grainsize distribution curve must fit the one of heavy metals and PAH. A testing material that is too coarse would not cover the biggest part of the finer fraction of pollutants attached to solids. A testing material that is too small would be too strict especially for silt traps.

Different quartz materials were found, that show different grainsize distribution curves and fulfil the given requirements. They are distributed under the name Millisil. In Figure 6 grainsize distribution curves of possible testing materials are added to the main lines of copper and PAH distribution curves from Figures 5 and 6 and other heavy metals. These belong to a fine Millisil W 11 and a coarser Millisil

W 4 and W 3 [Quarzwerkegruppe Frechen, 2009].

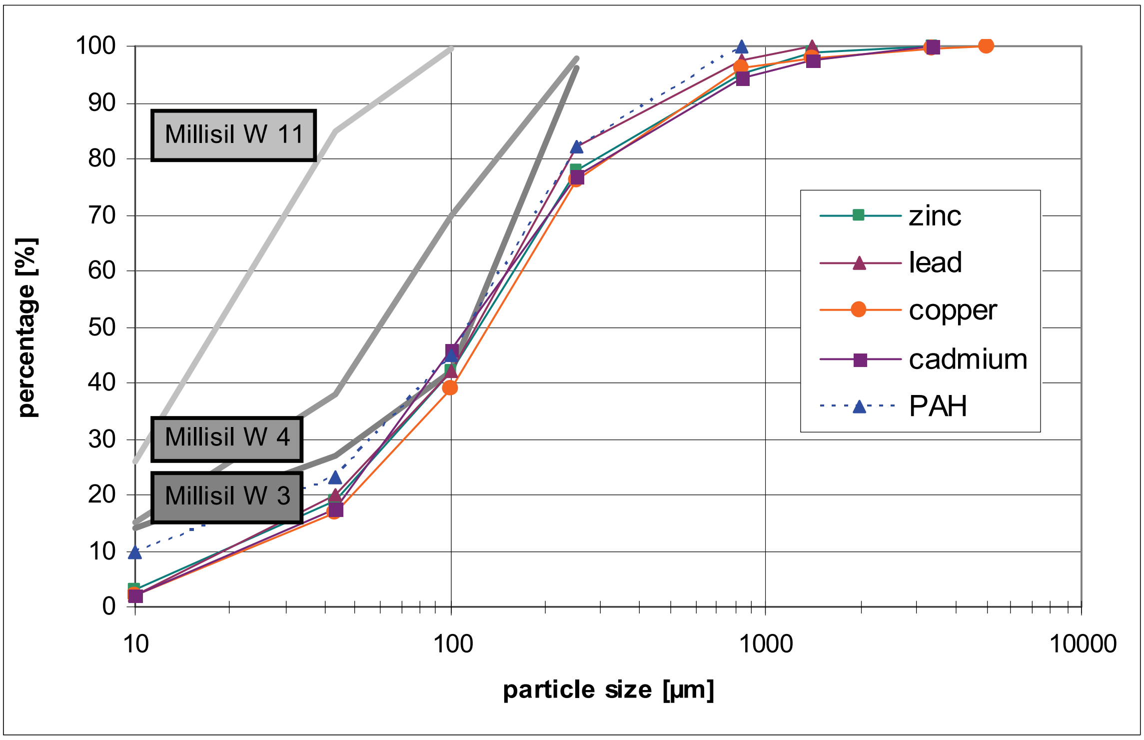

Figure 6. main lines of heavy metal and PAH distribution in different particle size fractions in street dust and in street runoff and grainsize distribution curves of three different quartz materials

analysis with air jet sieve		analysis with Cilas granulometer	
mesh size	sum of residues	particle size	sum of residues
[µm]	[compound-%]	[µm]	[Vol-%]
400	0,1	32	70
315	0,2	16	80
200	4	8	88
160	10	6	91
125	22	4	93
100	30	2	96
63	51		
40	66		

Table 2. Grainsize distribution curve of Millisil W 4 which is recommended for testing decentralised stormwater treatment facilities [Quarzwerkegruppe, Frechen, 2009]

From the diagram it can be seen that the quartz material Millisil W 3 in the fraction up to 100 µm is not fine enough to represent the main line of heavy metals and PAH. The quartz materials Millisil W 4 and W 11 are fine enough to represent the particle based pollutants and the TSS, as they can be found in reality. The grainsize distribution curves of the quartz material Millisil W 11 is too small and could be too strict for the testing of stormwater treatment facilities in the laboratory. The grainsize distribution curve of Millisil W 4 correlates more to the grainsize distribution curve of heavy metals and PAH´s in reality and represents the „envelope“ of all pollutant curves within a safety distance. With this testing material all relevant pollutant concentrations can be represented.

Out of this reason a quartz material according to Table 2 from the grainsize distribution curve is recommended for testing decentralized stormwater treatment facilities. It represents the solid fraction of PAH´s and heavy metals and can be used for standardized testing procedures.

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