Vurdering af nødvendig sedimentationsvolumen

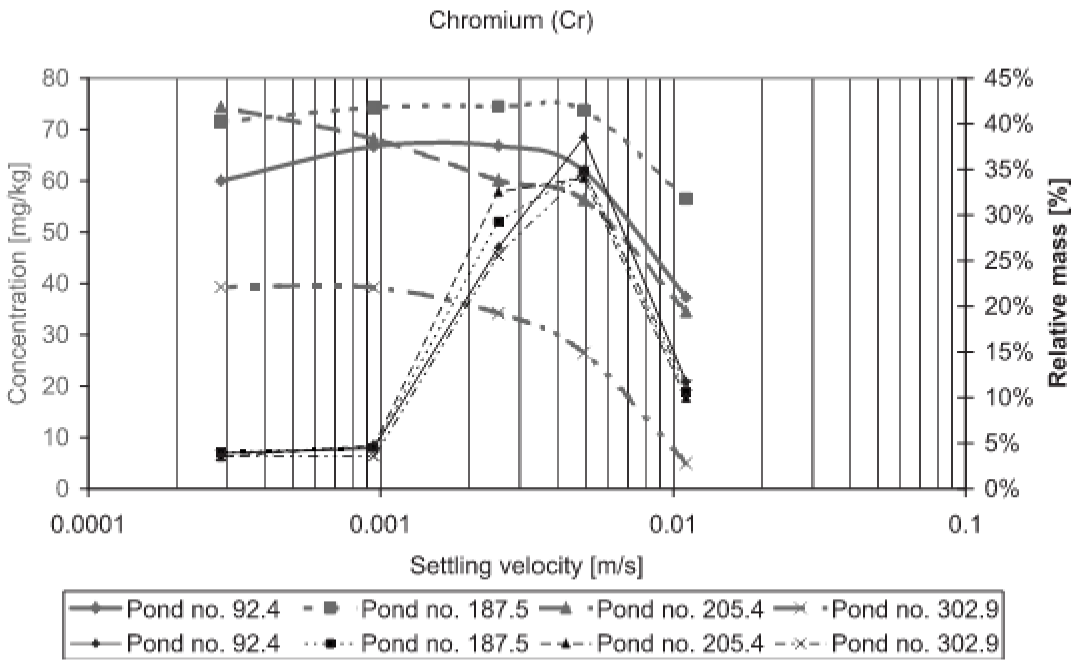
Typiske anbefalinger om 200-250 m³ / red. ha vådvolumen baserer sig på direkte tilkobling af oplande til bassiner og de dermed kraftige tilløb der foregår under regn.

Der er her tale om en kraftig droslet tilførsel af vand i størrelsesordenen 25 m³/t (7 l/s).

Baseret på *Bentzen og Larsen, 2009 (vedlagt)* er der foretaget en faglig vurdering af en nødvendig rensevolumen (permanent volumen) til sikring af rensning svarende til et traditionelt vådt regnvandsbassin som er anerkendt som BAT løsning.

Et vådt regnvandsbassin har stor rensegrad overfor partikulært stof der vaskes af vej og andre befæstede arealer. Størstedelen af tungmetaller og eksempelvis PAH'er er partikulær bundet og vil deraf (såfremt de hydrauliske forhold tillader det) sedimenterer ud og tilbageholdes.

Baseret på koncentrationsmålinger på forskellige kornstørrelser og dermed sedimentionshastigheder af aflejret sediment fra regnvandsbassiner ses af nedenstående figur (her vist for krom), at de største koncentrationer findes på de mindste partikler, MEN da andelen af disse partikler er meget lille, udgør de en meget lille andel af den samlede masse. Denne fordeling er ligeledes medtaget i nedenstående figur.



Det ses her, at langt størstedelen af krom i dette tilfælde er bundet til partikler med en sedimentionshastighed over ca. 2 mm/s. Ovennævnte forsøg er udført i stillestående vand. Men et konservativt estimat med en sedimentionshastighed på 20 gange mindre (0,1 mm/s) vil det tage i størrelsesorden 3 timer at sedimentere 1 m. En opholdstid vil i denne størrelsesorden (i et bassin uden voldsom strøm/turbulens) sikre en effektiv rensning der kan sidestilles med et traditionelt dimensioneret bassin.

Et permanent vådt volumen på 25 m^3/t * 3 timer = 75 m^3 burde således være tilstrækkeligt til en effektiv bundfældning så længe at indløbshydrografen er tilpas lav til ikke at skabe for megen strøm/turbulens i vandet.

En vanddybde på mindst 1 meter sikre mindre drift, (sjældnere oprensning samt mindre bevoksning). Da det effektive bundareal vil være mindre end et traditionelt dimensioneret bør der dog påregnes hyppigere oprensning.

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Bentzen T.R. og Larsen T. (2009) Heavy Metal and PAH Concentrations in Highway Runoff Deposits Fractionated on Settling Velocities. Journal of Environmental Engineering, ASCE 135(11) 1244-1247

Heavy Metal and PAH Concentrations in Highway Runoff Deposits Fractionated on Settling Velocities

Thomas Ruby Bentzen, Ph.D.[1]; and Torben Larsen[2]

Abstract: The correlation between settling velocity and associated pollutant concentrations is of major importance for best management practice in designing, redesigning, or evaluation of the efficiency of existing pond facilities for retaining unwanted pollutants. The prospect of this note is to state the relationship between the settling velocity of the runoff particles and the corresponding metal and polyaromatic hydrocarbon (PAH) concentration directly instead of dealing with two unknowns—the density and the shape of a single particle fraction in a settling velocity calculations. The measurements show that the highest cadmium, chromium, zinc, and nickel concentrations is associated with the most slowly falling particles and the lowest concentration associated within the faster falling fraction. This tendency is not clear for some of the sediments due to high content of organic matter and clearly not for lead and copper and there is no significant correlation between PAH concentration and settling velocity. The largest mass of metals and PAH within each pond can be found on the particle fraction with a settling velocity of 5.5–2.5 mm/s.

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CE Database subject headings: Best Management Practice; Detention basins; Sediment; Stormwater management; Heavy metals; Highways and roads; Runoff; Settling velocities.

Introduction

The pollution of the water environment (primarily ditches, streams, and rivers) caused by highway runoff focuses especially on heavy metals and polyaromatic hydrocarbons (PAHs), e.g., in studies of Ellis and Revitt (1981), Ellis et al. (1987), Mushack (1987), Wu et al. (1998), and Crabtree et al. (2005) due to their frequent occurrence in highway runoff and their toxicological effects on the environment and human beings (Makepeace et al. 1995). Sedimentation ponds are commonly used as treatment facilities for polluted highway runoff. Many ponds have been designed only for flow control and peak reduction but studies have shown particularly high removal efficiencies for suspended solids and thereby also for heavy metals and organic compounds due to their sorption affinity (Van Buren et al. 1997; Petterson et al. 1999; Comings et al. 2000). The paper presents results from an experimental study of the distribution of six heavy metals, the sum of seven PAHs including two specific PAHs on different particle settling velocities.

The study presented here is part of a general investigation on road runoff and pollution in respect to wet detention ponds. The objective of the general investigation is to determine the pollutant discharges from roads and highways based on long-term numerical modeling (hindcasts). Accordingly a proper description of the transport of this pollution must emphasize on an accurate modeling of the transport of fine particles from the road surface through drainage system and trough the detention pond to the receiving water. For numerical modeling purposes, e.g., modeling of efficiencies of a specific pond facility for retaining undesirable pollutants, new design or optimizing existing ponds, the settling velocity for incoming particles are of high importance and in combination with different pollutant levels associated even higher.

Many studies, e.g., Ellis and Revitt (1981), German and Svensson (2002), and Zanders (2004) showed relationships between particle size (diameter) and metal concentration originating from road runoff. Li et al. (2006) summarized heavy metal concentration as a function of particle size ranges. These diameter relationships are within the context of transport modeling in ponds of discussable importance since lack of density and shape of the single particle fraction is prevalent. Recently Kayhanian and Rasa (2007) dealt with the issue of density and showed that fractionated solids from highways vary from 1.6 to 1.8 $\mathrm{g/cm^3}$. Hereby, in terms of best management practice, use of the traditional quarts density will lead to an overestimation of the efficiency of, e.g., a detention pond.

The prospect of this study is to state the relationship between the settling velocity of the runoff particles and the corresponding metal and PAH concentrations directly instead of dealing with two unknowns—the density and the shape of a single particle fraction in settling velocity calculations with, e.g., Stoke's law and other empirical models which also have limitations within the flow regime around the falling particles.

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Table 1. Summary of Site Characteristics

Parameter	Pond No.[a] 302.9	Pond No. 205.4	Pond No. 187.5	Pond No. 92.4
Highway	E45	E45	E45	E45
Nearby city	Vodskov	Randers S	Grundfoer	Fredericia
Pond area [m^2]	2,299	2,300	2,300	600
Catchment area [m^2]	27,000	37,000	41,000	16,000
Age of pond (years)	7	13	13	13
Annual day traffic (vehicles/day)	14,800	32,100	33,800	24,100
Precipitation (mm/year)	820	690	690	770

[a] Pond numbers refer to the distance from origin of the highway.

Sampling Procedure

Sediments from four Danish wet detention ponds are used for the experiments (see Table 1). The composite core sampling procedure can be found in Bentzen et al. 2007. The composite samples for each pond were kept at 4°C prior to the experiments. The ponds only receive runoff from highways, with closed pipe drainage systems and no prior sedimentation occurs over time.

The settling velocity distribution for each of the four ponds is measured with application of a 1.65-m-high water-filled vertically standing cylindrical tube (diameter of 0.145 m). The temperature of the tube water during the settling experiments was 19°C and a pH of 6.9. The effect of temperature is discussed later on. The composite sediment samples were mixed with water with same temperature as the tube water and calmly added into the top of the tube. Five water samples for each of the four pond sediments were taken out in the bottom representing following five settling velocity intervals: >5.5, 5.5–2.5, 2.5–1.3, 1.3–0.5, and 0.5–0.1 mm/s. The effect of flocculated or hindered settling were minimized by repeating the experiments three times in order to get the necessary mass of sediment for metal and PAH analyses. The samples were analyzed on an accredited laboratory for the metals: cadmium, chromium, copper, lead, nickel, and zinc and the sum of seven PAHs according to the standard of the Danish Environmental Protection Agency (fluoranthene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene). Only specific results for benzo(a)pyrene and dibenzo(ah)anthracene are included due to their high carcinogenic potential. For additional characteristic of the respective sediments—grain-size distributions of the composite samples were determined by laser diffraction analyses (particle size analyzer—Microtrac II Model 7997-20) and the organic content on various settling velocities were determined by loss of ignition at 550°C, as shown in Figs. 1 and 2. In respect to the content and distribution of organic matter, the sites differ. The reason for this can be explained by the location and surroundings of the highway catchment. The catchment for Pond No. 92.4 is a bridge over a valley in a forest area and, e.g., Pond No. 302.9, the catchment is located in level with agricultural areas where the presence of heavier sand particles is much higher than in the forest area.

Fractionated Heavy Metal and Polyaromatic Hydrocarbons Concentrations

Figs. 3–11 present the fractionated pollutant concentrations and the relative mass of pollutants. The relative mass of a single pollutant is calculated as given in Eq. (1)

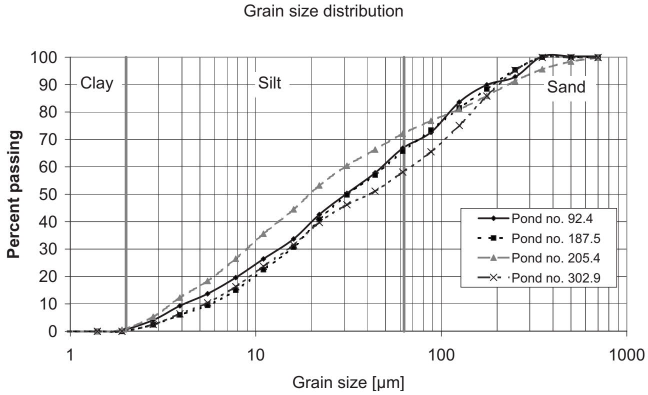

Fig. 1. Grain-size distributions

$$P_{p,i} = \frac{C_{p,i}}{C_0}\frac{M_{SS,i}}{M_{SS,T}} \tag{1}$$

where $P_{p,i}$=relative mass of the pollutant within the sediment (mg/mg), $C_{p,i}$=pollutant concentration on the ith fraction of the sediment (mg/kg), C_0=pollutant concentration in the nonfractionated sediment (mg/kg), $M_{SS,i}$=mass of the ith fraction of sediment (kg), and $M_{SS,T}$=total mass of sediment (kg).

In the figures the settling velocity intervals are given by the center of the settling velocity interval. The concentration for the PAH dibenzo(ah)anthracene were, for some of the samples, below detection limits, hence the noncontinuous curves on Fig. 11. Due

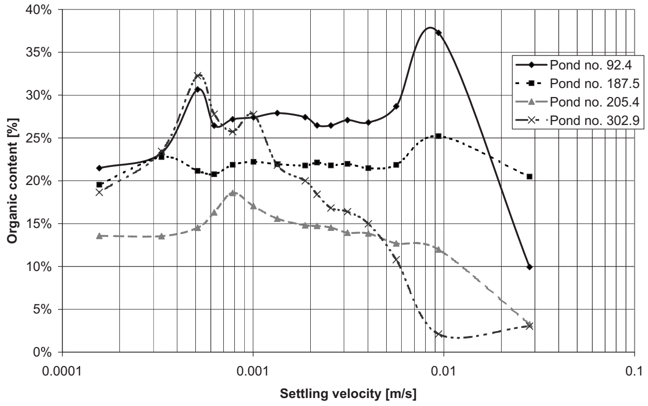

Fig. 2. Organic content as function of settling velocity

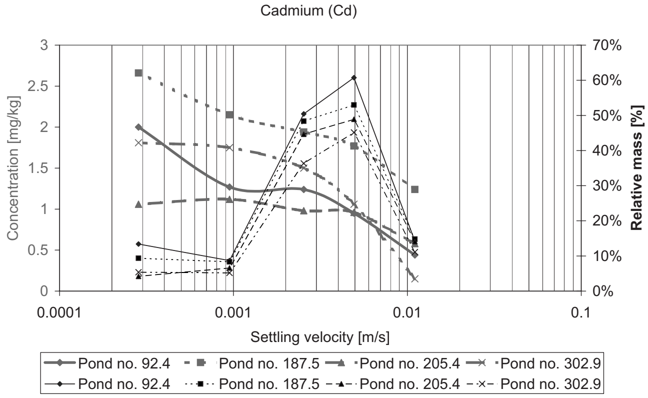

Fig. 3. Fractionated cadmium concentration and relative mass with respect to settling velocity

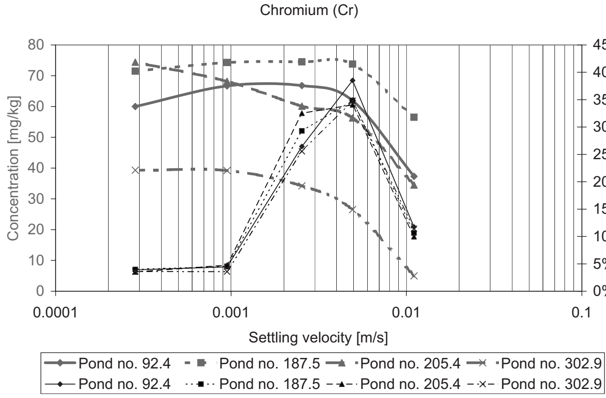

Fig. 4. Fractionated chromium concentration and relative mass with respect to settling velocity

to the fact that fractions with a settling velocity below 0.1 mm/s have not been measured, the sum of the relative pollutant mass can be below 100%. For cadmium and zinc (Figs. 3 and 8) the sum of the relative mass exceeds 100%, which of cause is unrealistic but still within the uncertainty of the metal analysis and the uncertainty of the settling velocity distribution measurements.

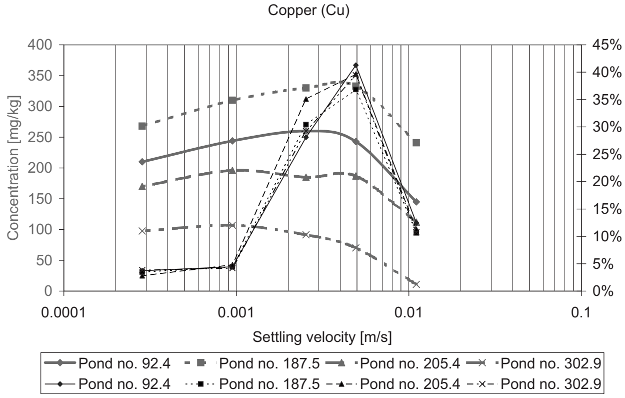

Fig. 5. Fractionated copper concentration and relative mass with respect to settling velocity

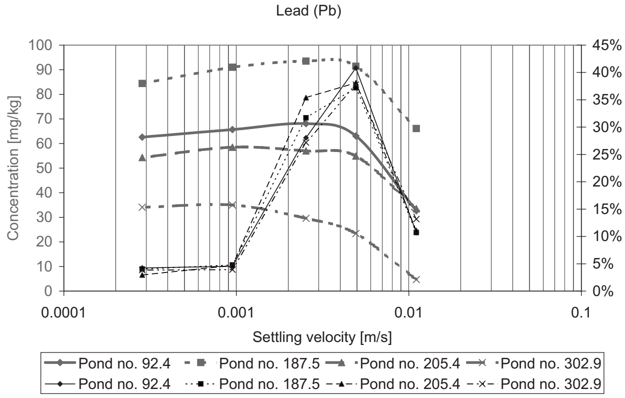

Fig. 6. Fractionated lead concentration and relative mass with respect to settling velocity

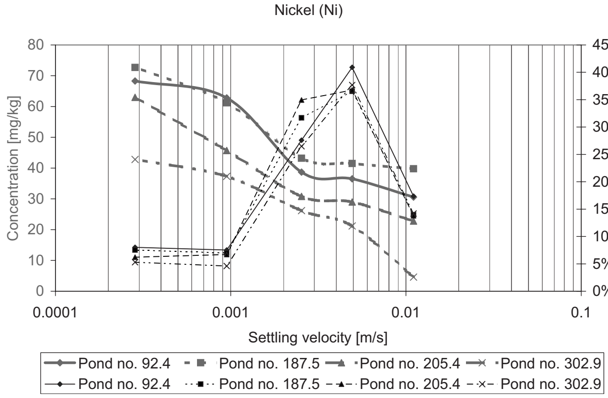

Fig. 7. Fractionated nickel concentration and relative mass with respect to settling velocity

Discussion

For the metals cadmium, chromium, zinc, and nickel, it is evident that the highest metal concentration is associated with the most slowly falling particles with a settling velocity of 0.5–0.1 mm/s and the lowest concentration associated within the faster falling fraction with a settling velocity above 5.5 mm/s. For Pond Nos. 92.4 and 187.5, this is not so significant and for copper and lead, the tendency is also not so clear. For Pond Nos. 92.4, 187.5, and partly 205.4, it seems that the adsorption curves for the pollutants

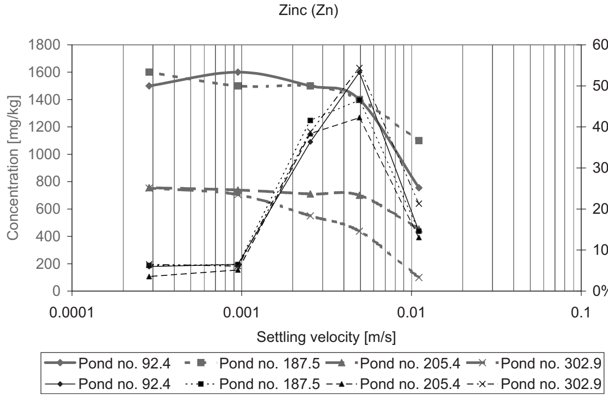

Fig. 8. Fractionated zinc concentration and relative mass with respect to settling velocity

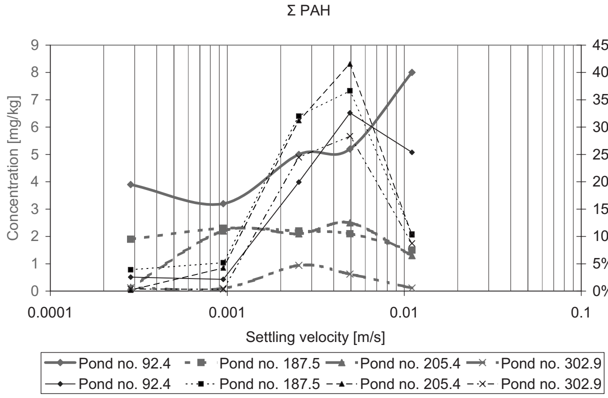

Fig. 9. Fractionated concentration of ΣPAHs and relative mass with respect to settling velocity

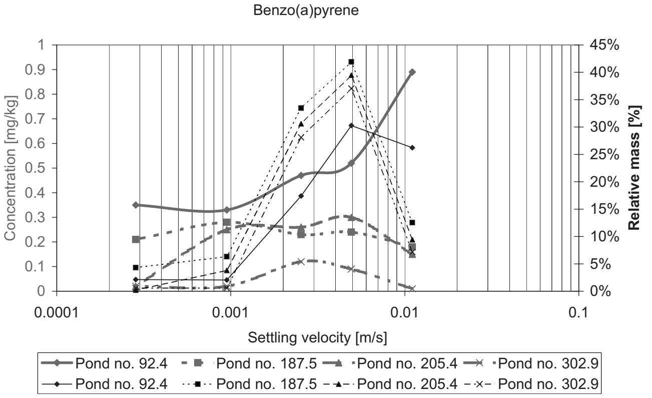

Fig. 10. Fractionated benzo(a)pyrene concentration and relative mass with respect to settling velocity

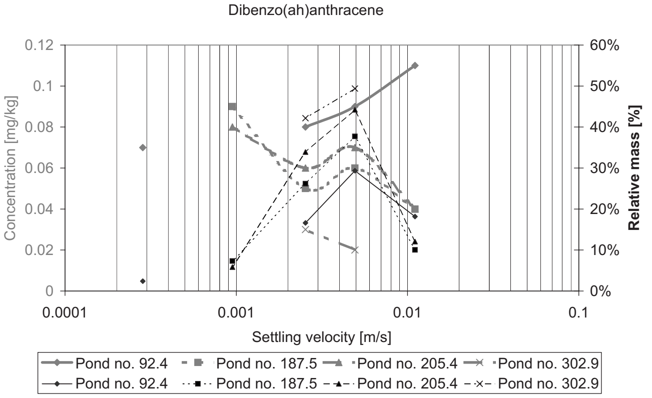

Fig. 11. Fractionated dibenzo(ah)anthracene concentration and relative mass with respect to settling velocity

have an optimum around a settling velocity of 2 mm/s and not at the slowest falling particles. The reason for this is most likely due to the higher content and distribution of organic matter (see Fig. 2) for the two ponds 92.2 and 187.5 since the main adsorbent of lead is organic matter (Sipos et al. 2005) which is similar for copper (Maralek and Marsalek 1997). Despite the threefold differences in concentration levels of the metals between the four ponds, the relative mass of the metals are almost similar due to the underlying settling velocity distributions. The settling velocities given in note are based on the use of 19°C warm water in the experiments. The settling velocity is temperature dependent, especially with laminar flow around the particles which is prevailing for the used material in this study. Thus a change in kinematic viscosity (and to a less extent, the density) will, for a temperature drop down to, e.g., 4°C of the surrounding water, lead to a decrease of the giving settling velocities of 33 %.

Conclusions

The measurement campaign states a direct relationship between settling velocity of runoff particles from highways and the corresponding heavy metal and PAH concentrations. The measurements show in general that the highest metal concentration is associated with the most slowly falling particles but divergence from the general conclusion are shown due to high organic content. For the PAHs there is no significant correlation between concentration and settling velocity. In terms of mass instead of concentrations, it can be concluded that the largest mass of metals and ΣPAH within each pond can be found on the particle fraction with a settling velocity of 5.5–2.5 mm/s at 19°C (approximately 3.7–1.7 mm/s at 4°C).

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