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SciVerse ScienceDirect
Procedia - Social and Behavioral Sciences 48 (2012) 393 – 402
Procedia
Social and Behavioral Sciences

Transport Research Arena– Europe 2012

Quality of sediment in detention basins – mapping of the Danish national road network

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Abstract

Use of the road infrastructure brings wear of the road surface and vehicles and loss of fuel components. This leads to pollution of the environment near the roads, due to run-off of road surface water to lakes and streams. The two thousand detention basins along the Danish main road network act as delaying basins for sudden large amounts of water and also collect substances which are injorious to the environment, before the water is led to lakes and streams. The Danish Road Directorate has examined the content of substances injorious to the environment in the sediment of 70 basins distributed in the whole country. Analysis of hydrocarbons, PAH, heavy metals and NaCl have been made. The analysis are used to determine the degree of pollution of the sediment in relation to the criteria set out by the Danish Environmental Protection Agency. The results show that at least 90 per cent of the detention basins have sediment which is defined as slightly polluted and at least 61 has sediment which is polluted. These high values are due to the content of hydrocarbons. The second largest source of pollution is nickel and the concentrations show that 20 per cent of the basins have sediment which is polluted by nickel. The highest concentrations of substances injorious to the environment are around Copenhagen and Odense and on the stretch between Kolding and Randers. The content of PAH and heavy metals has been compared to analysis from 38 natural Danish lakes. The analyses shows that there is no marked difference between the measured levels of pollution in detention basins and natural lakes. Hydrocarbons have been compared to two natural lakes and here the difference is very considerable.

Keywords: Detention basins; sediment; pollution; highways; Denmark; natural lakes; soil quality

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doi:10.1016/j.sbspro.2012.06.1019

1. Introduction

Rainwater detention basins along the road are constructed to collect rainwater, delay large rain events and to prevent oil-based products and suspended substances to run further out into the recipient. The Danish motorway network is continuously being extended and this presents some specific problems in relation to the handling of sediment collected from the detention basins. There are some 2,000 detention basins along the Danish national roads and a rule of thumb says that one detention basin is constructed every second kilometre. In general, they are closed systems which ensure that only water from roads, direct rain and run-off from the sides end in the basins. Consequently, the sediment in the basins comes from materials brought with water from the roads, through side erosion or from the atmosphere.

Material from wear of vehicles, corrosion from brakes, wear of road surfaces, loss of fuel as well as salt from winter maintenance constitute the elements, which cause waterborne pollution from the roads. All of these residual products will either swirl up together with dust and be led away by the wind or they will go with rainwater into the drainage system and thereby end in the detention basins.

The detention basins act as sedimentation basins, such that the water runs very slowly or stands still when the weather is dry. Thus, the particles deposit if they are not sufficiently small to remain in suspension until the water runs out of the outfall. Many substances, injorious to the environment, sorb to larger particles (mineral grains and organic materials) which means that they sediment together with the particles and therefore remain in the basin. The most problematic particles are often difficult to degrade, or they cannot be degraded at all, and they therefore accumulate easily in various recipients. Detention basins are therefore an important reservoir for these substances.

2. Methods

Sediment from 70 detention basins along the Danish main road network has been sampled and from each basin ten chemical parameters (lead, cadmium, copper, zinc, nickel, chromium, PAH and hydrocarbons as well as chlorines and sodium) have been made at an accredited laboratory and nine physical parameters have been determined (e.g., the surface area of the basin, distance to the road, annual daily traffic). In each basin, sediment has been collected with a russian core to obtain the material needed for analysis. The concentrations have been evaluated in relation to the criterion set out by the Danish Environmental Protection Agency (EPA) for slightly polluted soil (soil quality criterion) and polluted soil (cut-off criterion) (EPA 2010).

Chemical concentrations from detention basins have been compared to chemical concentrations from natural lakes, so that the impact from traffic and roads on the rainwater detention basins can be evaluated.

The statistical method presented in Table 2 is confidence intervals compared for natural lakes and detention basins. See description in Table 2. To test for significant correlation between all chemical and physical parameters (section 4.4), a multivariate regression analyses and principle component analyses were used. This article focuses on selected data for hydrocarbons, cadmium and zinc.

3. Results from the chemical analyses

3.1 Degree of pollution of the sediment

In Denmark, the EPA has established two threshold values, which separate clean soil from slightly polluted soil (soil quality criterion) and slightly polluted soil from polluted soil (cut-off criterion), respectively (EPA 2010). The threshold values are determined for a large number of substances injorious to the environment, and they are important for classification of sediment and for the procedures for

treating the sediment if this is removed. The concentration of substances injorious to the environment can also give an indication of the severity concerning substances in the water.

Table 1. The number of detention basins in per cent, which are above the soil quality criterion and cut-off criterion. Samples of the sediment at the bottom of the basins were analysed for hydrocarbons, PAH and heavy metals and the results show that at least 90 percent of the basins contain sediment which is slightly polluted (based on the sum of hydrocarbons) and at least 61 per cent contain sediment which is polluted (based on heavy hydrocarbons, C20-C35). In 20 per cent of the basins, nickel concentrations are so high that the sediment must be classified as polluted.

Substances	**Per cent above the soil quality criterion (slightly polluted sediment)**	**Per cent above the cut-off criterion (polluted sediment)**
Lead	49	0
Cadmium	62	0
Chrome	60	0
Nickel	20	20
Copper	1.4	0
Zinc	24	8.6
Hydrocarbons	90	61
PAH	17	0
Highest value	90	61

Table 1 presents an overview of the parameters determined as well as the degree of pollution. The variation in hydrocarbons is very large as it varies from below the limit of detection of 0.1 mg/kg dried matter (dm) to 11,000 mg/kg dm. There are only seven basins below the soil quality criterion of 100 mg/kg dm for the total of all hydrocarbons (Figure 1). In other words, 90 per cent of the basins contain sediment slightly polluted with hydrocarbons. There is no cut-off criterion for the total of all hydrocarbons, but for the concentration of heavy hydrocarbons (C20-C35), the threshold value is 300 mg/kg dm. In Figure 2, the total of heavy hydrocarbons is presented and the concentrations show that 43 basins have concentrations above the cut-off criterion. In many cases the concentrations are far above the limiting criterion. Thus, 61 per cent of the basins in the study contain sediment which is polluted with heavy hydrocarbons. 16 of the basins have concentrations over 2,000 mg/kg dm. This is more than six times the cut-off criterion, and the sediment in these basins must be characterized as severely polluted.

Most of the zinc concentrations in the basins are between 50 and 500 mg/kg dm (Figure 3). 24 per cent of the basins show values of slightly polluted sediment (>500 mg/kg dm) while 8.6 per cent of the basins have sediment which is polluted (> 1000 mg/kg dm).

Nickel and zinc are those heavy metals found in the highest concentrations in relation to the cut-off criterion. Copper, chromium, lead and cadmium were found in all 70 basins, but they are not above the cut-off criteria. The PAH content is low and therefore there is no concern from a pollution point of view (Table 1). There is large variation in the concentrations between analysed parameters. However, only one parameter needs to exceed the threshold value for the soil to be characterized as slightly polluted or polluted. Since the hydrocarbons are such a large source of pollution in relation to all other sources, many basins are characterized as polluted. The number of polluted basins could be reduced from 61 per cent to 20 per cent, if the content of hydrocarbons were reduced to a value below the cut-off criterion for polluted soil.

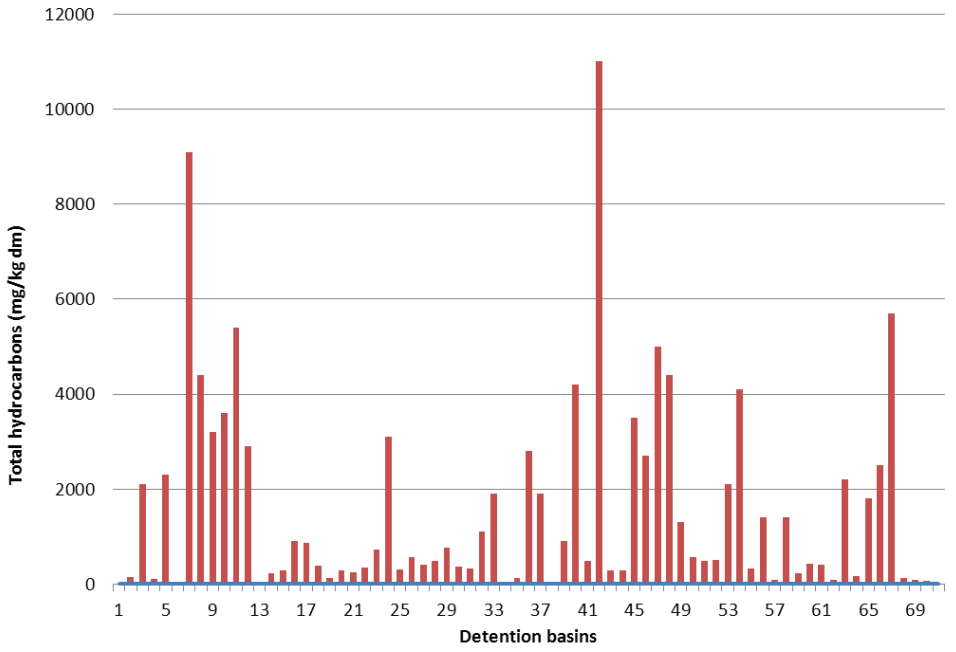

Fig. 1. Sum of hydrocarbons in 70 detention basins distributed over Denmark's main road network. The soil quality criterion for slightly polluted sediment is 100 mg/kg dm (blue line). There is no cut-off criteria for the sum of all hydrocarbons for polluted soil, but for heavy hydrocarbons the limit is 300 mg/kg dm.

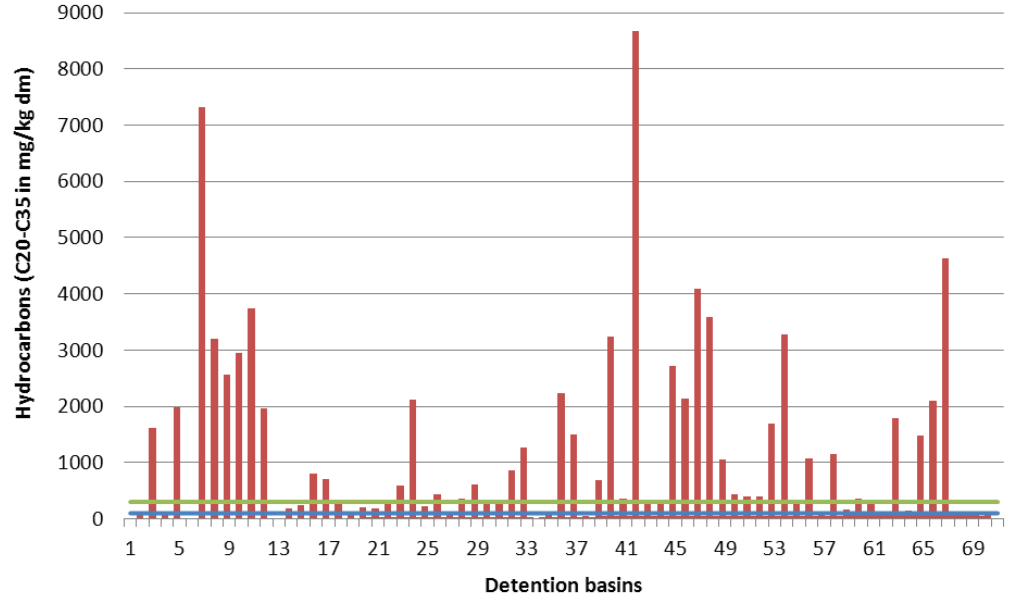

Fig. 2. Content of heavy hydrocarbons (C20-C35) in sediment from detention basins. The criterion for slightly polluted sediment is 100 mg/kg dm (blue line) and for polluted sediment 300 mg/kg dm (green line). 61 per cent of the basins contain polluted sediment.

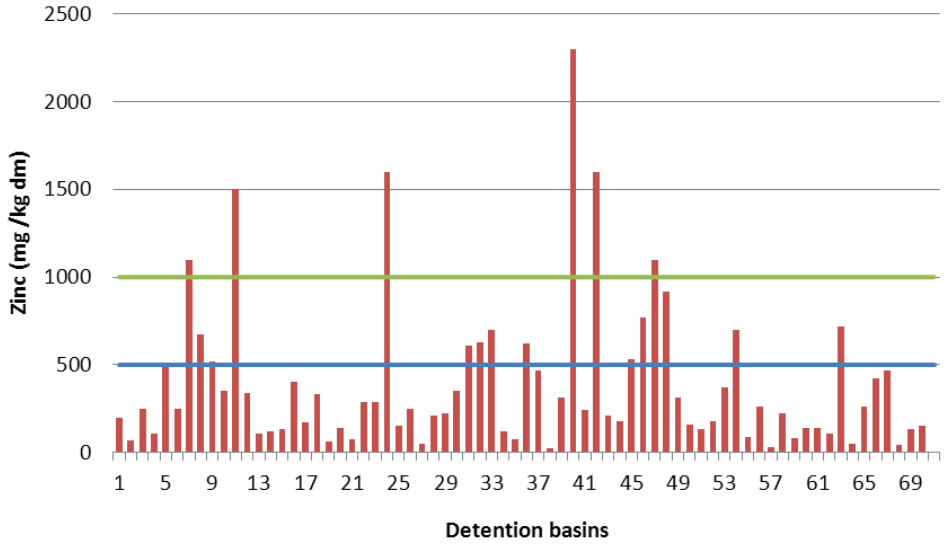

Figure 3. Concentration of zinc in the 70 detention basins. 24 per cent of the basins contain sediment which is slightly polluted and 8.6 per cent are polluted. The blue line is the soil quality criterion of 500 mg/kg dm for slightly polluted soil and the green line is cut-off criterion of 1000 mg/kg dm for polluted soil.

3.2 Geographic distribution in Denmark

In Figure 4 the geographic distribution is shown for hydrocarbons and zinc. The highest concentrations are found near major urban areas: Odense, Copenhagen and the stretch between Kolding and Randers. The same tendency is seen for the other heavy metals and PAH. An attempt has been made to correlate the tendency seen on the maps with the annual daily traffic, the thickness of the sediment and the age of the basin, however, without any significant correlations.

3.3 Comparison with natural Danish lakes, reference lakes

The amount of pollution in the detention basins is compared to 38 natural lakes (reference lakes). Data from the reference lakes is found in literature covering 36 lakes (Bjerring et. al. 2010, Retzel 2006), and by sampling made by the authors from two lakes. It is, however, not possible to perform a reasonable comparison between the hydrocarbon concentrations in the detention basins and in the reference lakes, since there is very little available data for the reference lakes. There are, however, results from measurements of hydrocarbons made by the authors from two natural lakes. They only show measurable concentrations in three of the nine samples and they all have rather low values (50-80 mg/kg dm). So, if an evaluation is made on a very limited basis it would appear that there are few hydrocarbons in the sediment from natural lakes, and that the high content of hydrocarbons in detention basins must be due to contribution from roads.

With the exception of two samples, the content of zinc in the reference lakes lies below the soil quality criterion of 500 mg/kg dm (Figure 5). There are a few peaks in the concentration of zinc in detention basins, but in general, the levels are very close to each other. It is therefore not really clear that the roads contribute to the somewhat increased zinc concentrations, but it is the most likely explanation, since a road pollution source is so close by. A statistical analysis shows that the expectation of identical average values for lakes and detention basins cannot be confirmed and that the average values of detention basins

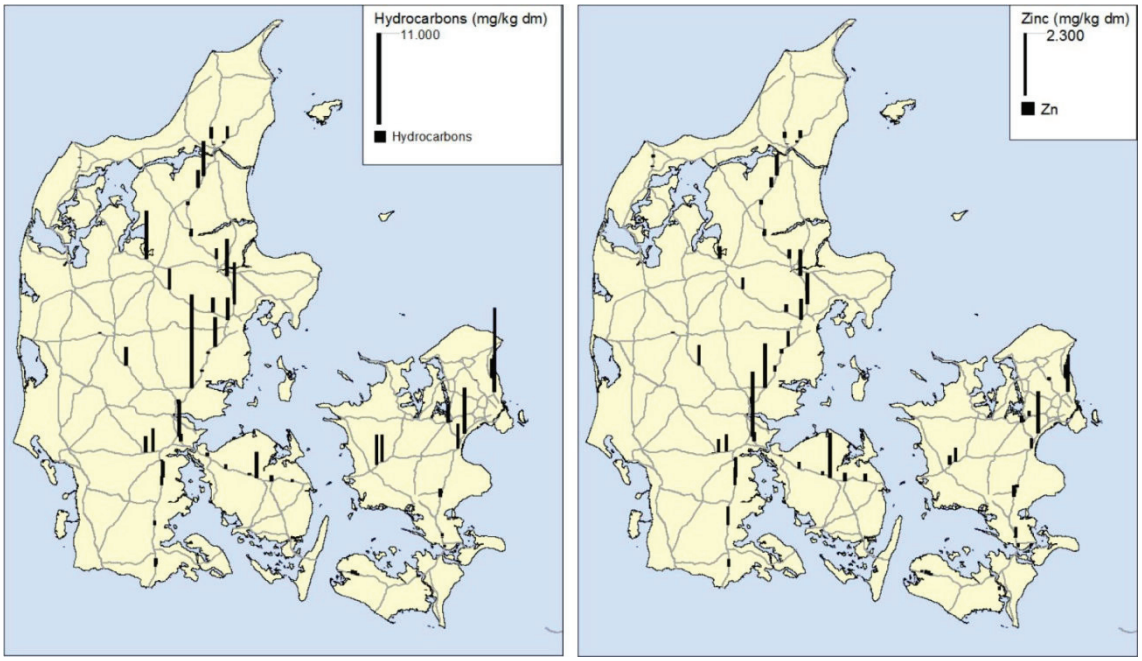

Fig. 4. The concentration of hydrocarbons and zinc in the sediment, illustrated as columns at the actual location of the basins in Denmark.

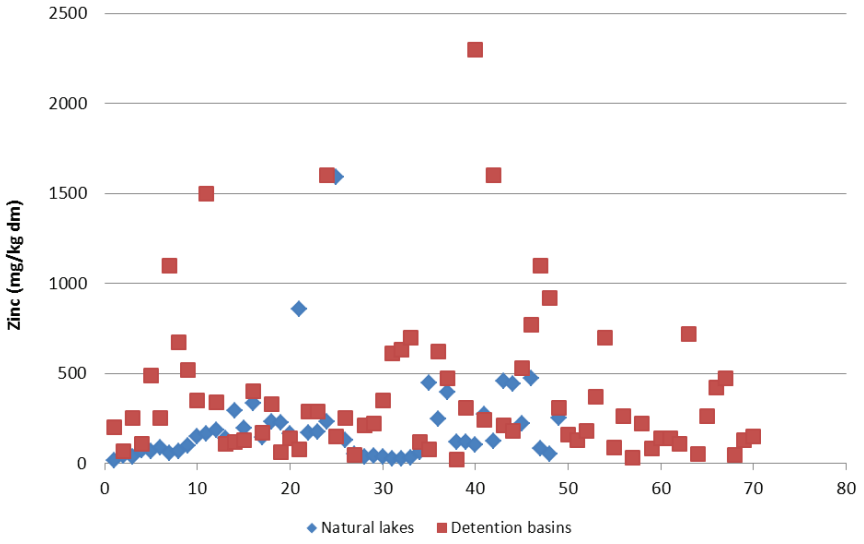

Fig. 5. Comparison between the content of zinc in the sediment of detention basins and in reference lakes. The soil quality criterion is 500 mg/kg dm. Visually, it seems that the levels are similar, however, with some detention basins having higher concentrations. A statistical confidence interval analysis shows that the average values for lakes and detention basins are not identical (Table 2).

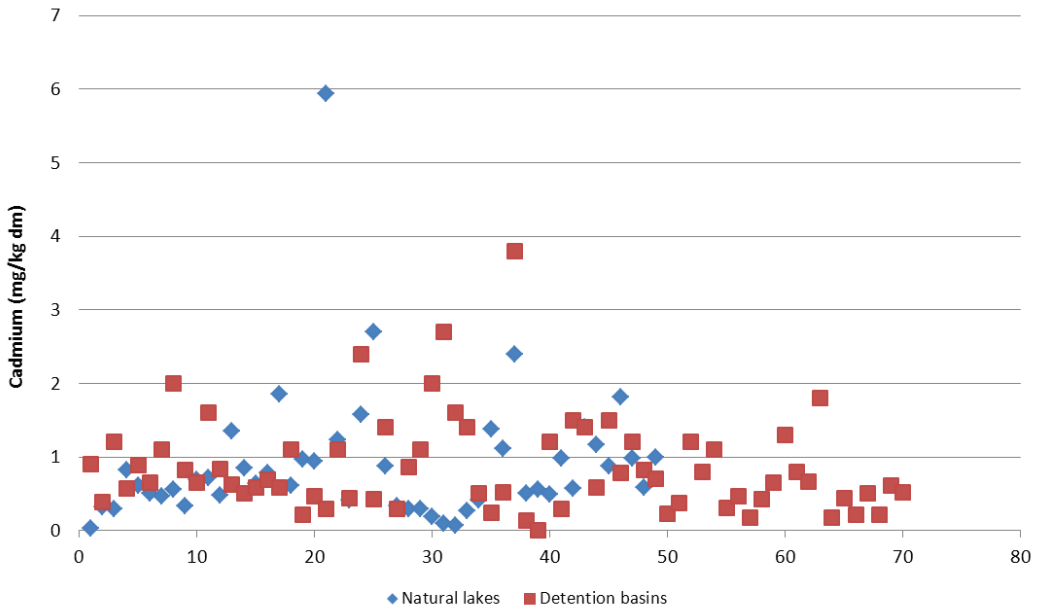

Fig. 6. Comparison of cadmium in the sediment of detention basins and reference lakes. The soil quality criterion is 5 mg/kg dm. Visually the levels seem to be identical and a statistical confidence interval analysis confirms this (Table 2) .

are higher (Table 2). The result shows that the average values between natural lakes and detention basins is not as clear identical as it is for, say, lead, nickel and cadmium (Table 2).
The cadmium concentrations in the reference lakes (Figure 6) are equal to or just above the average for the detention basins and the statistical analysis shows that the average concentrations are identical (Table 2). A single reference lake is even above the cut-off criterion (5 mg/kg dm). The generally high level over 0.5 mg/kg dm shows that many detention basins (61 per cent) and reference lakes (84 per cent) are slightly polluted.
The cadmium concentration in the natural lakes presumably comes from the time when untreated waste water was led out into the aquatic environment and sorbed with organic material or clay particles.

4. Discussion

4.1 Pollution from source to surroundings

Heavy metals, hydrocarbons and PAH exist as parts of vehicles, their tyres, fuel, asphalt pavements and road furniture and it is therefore almost unavoidable that wear on roads, vehicles, tyres and brakes will release substances injorious to the environment. In dry periods the particles lie as dust on the road surface, shoulders and verges. Some dust will resuspend into the air and thereby spread to surrounding areas. In wet periods, the dust gets washed away into the road's drainage system and to natural recipients. Dutch studies show that the majority of the pollution is spread in two ways: by atmosphere as spray from vehicles and by water vapour above the road surface. In dry periods, the pollution lies on the road or it is resuspended into the air and spread to the surroundings, where it deposits (van Bohemen & Janssen van der Laak (2007).

Table 2. 95%-confidence interval for the difference in the mean value between measurements from reference lakes and detention basins ($\mu_{Lakes} - \mu_{Basins}$). Confidence intervals, which do not include the value 0, where the average concentrations in reference lakes and detention basins are different, are marked red. On the other hand, confidence intervals, which include the value 0 are marked green and here it cannot be rejected that they have the same average concentrations. If the intervals are marked red and only contain negative numbers it means that the mean value of the detention basin is higher than that of the reference lake.

Substance	**Interval**
Cadmium (Cd)	-0.25 to 0.33
Chrom (Cr)	-13.83 to -3.07
Cubber (Cu)	-102.70 to -40.89
Nickel (Ni)	-8.70 to 6.29
Lead (Pb)	-31.35 to 9.85
Zinc (Zn)	-320.93 to -51.43
Hydrocarbons <C10	-32.89 to -5.49
Hydrocarbons C10-C25	-764.78 to -36.79
Hydrocarbons C25-35	-2181.13 to -97.41
Hydrocarbons total	-2965.78 to -153.23
PAH - Fluoranthen	-0.17 to 0.25
PAH - Benz(b+j+k)fluoranthen	-0.08 to 0.37
PAH - Benzo(a)pyren	-0.07 to 0.12
PAH - Indeno(1,2,3-cd)pyren	0.06 to 0.31
PAH - Dibenzo(a,h)anthracen	0.02 to 0.08
PAH total	-0.20 to 1.08
NaCl	-4049.84 to 142.26

In Denmark, the European project POLMIT examined two verges along a motorway. The soil in the verge contained considerable concentrations of hydrocarbons and de-icing salt (NaCl) and relatively lower values of heavy metals and PAH. It was concluded that there is a large accumulation of pollution in the verges, since the oldest soil there contains the highest concentrations (Lehmann et al. 2001).

Comparisons between porous asphalt and traditional densely graded asphalt in the Netherlands have shown that a large amount of the spray from vehicles can be reduced by use of porous asphalt, since the roads dry faster on the surface. The porous asphalt also retains a lot of the pollution in the pores and thus limits the total spread of substances to the surroundings (van Bohemen & Janssen van der Laak 1993). The consequences of this must be that only a part of the pollution actually ends in the run-off and is led to the detention basins.

4.2 Function of detention basins

The present study shows that the amount of pollution in the sediment of the detention basins varies from slightly polluted to polluted and that considerable amounts of substances injorious to the environment are led to the basins. Hydrocarbons are the largest source of pollution in relation to the threshold criteria from the Environmental Protection Agency, while zinc and nickel are the major contributors among the heavy metals. Only in a few cases, PAH have concentrations of significance for the amount of pollution in the sediment. This means that a limitation of the hydrocarbons would considerably reduce the number of detention basins with a high level of pollution.

Collection at the edge is the most commonly used method in Denmark for collection of rainwater from the road surface. This method ensures that precipitation, and therefore also some of the pollution, is led to detention basins where sedimentation takes place before the water is led on to a natural recipient. The amount of pollution that never reaches the detention basins could be interesting to estimate. A Swedish study has shown that very little of the surface water ends in the drainage system; most of the precipitation falls in so small amounts that it ends up infiltrating the verge. This water never ends in the trenches or in the drainage pipes (Billberger 2011).

Bentzen (2008) has carried out a study which shows that 80 per cent of the suspended material is retained in the detention basin and that wind has a big effect on this number. The more shelter a basin has, the better is the sedimentation. Bentzen states that with few means, e.g., the optimum design of the detention basin and shelter from wind, basins can become more effective.

4.3 Comparison to natural lakes

Detention basins do not have a markedly higher level of heavy metals and PAH than the reference lakes. We know that reference lakes over time have been subjected to many sources of pollution, especially due to untreated waste water as well as fish farms, and this explains many of the high concentrations in the reference lakes. Most of these sources of pollution have been removed today, but the environmentally injorious substances that are difficult to dissolve are still deposited in the sediment, however now in deeper layers (Retzel 2006). The comparison with the reference lakes supports the point of view that heavy metals and PAH are not a major problem for detention basins and that an effort to prevent pollution with hydrocarbons would improve the environment considerably. A comparison, however, also shows that the sediment at the bottom of many Danish lakes is slightly polluted. The background level of the lakes is not necessarily the level to aim at for the detention basins.

4.4 No correlation between pollution level and road traffic

The maps in Figure 4 are examples of the ten maps which have been produced on the basis of chemical parameters. They show the geographic distribution of concentrations of substances in Denmark and the patterns seem identical for all substances. The highest concentrations are observed near the urban areas of Copenhagen, Odense and Kolding-Randers. It is therefore natural to assume that there must be a direct connection between the level of pollution and the number of vehicles on the road (annual daily traffic). However, it cannot be proved that the amount of substances injorious to the environment and the traffic on the roads is correlated. This is somewhat surprising as one should think that the more vehicles on the road, the greater the pollution in the detention basins. All the parameters collected have been tested statistically and it has not been possible to identify any parameters with a significant correlation. Neither has it been possible to find a successful correlation in literature. It seems that the concentration of substances in detention basins is also determined by many other factors than those studied here. Among others, air pollution from major cities could have a significant influence, which could be seen as higher pollution level near major cities and industrial areas.

5. Conclusions

70 detention basins have been examined for a number of chemical substances and the concentration have been evaluated in relation to the Danish criteria for slightly polluted and polluted soil, respectively. The number of basins which exceeds the threshold values differs greatly from substance to substance. Since it only requires one value exceeding the threshold to make it necessary to treat the soil accordingly, the overall picture is that the sediment is at least slightly polluted or polluted. This is due to the fact that hydrocarbons are such a large source of pollution compared to other substances. The result of the study is

that at least 90 per cent of the detention basins contain slightly polluted soil and at least 61 one per cent contain polluted sediment. Apart from hydrocarbons, nickel and zinc are the only substances with concentrations beyond the limit for polluted soil.

A comparison between the reference lakes and the detention basins shows that the content of PAH and heavy metals is not markedly different. This, however, does not apply to hydrocarbons; a comparison with just two reference lakes shows considerably higher concentrations of hydrocarbons in the detention basins.

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