Report on investigations into retention of pollutants in rainfall runoff from a concrete plant using a ecoStorm plus filter pit

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1. Background and Commission

In July 2004, ecoTECHNIC and Hydrocon were commissioned by Eurofiltrator e.K. of Datteln, Germany to analyse under laboratory conditions the cleaning performance of a ecoStorm plus filter pit using rainfall runoff from a concrete plant. The brief required that the behaviour of pollutants most relevant to infiltration, reuse and surface discharge be examined.

2. Structure of the HydroCon filter pit

The ecoStorm plus filter pit consists of concrete ring elements conforming to German standard DIN 4034, which are sealed at the connecting points to prevent water entering the pit from the outside and conversely, water leaving the pit (see Illustration 1). Surface rainfall runoff enters tangentially at the lower end of the pit just above a cyclone sediment separator. The angle of entry and shape of the separator sets up a swirling motion as water enters the chamber. These forces are accentuated by the volume and velocity of the influent, especially during severe rain events. Particles settle by gravity and are trapped in the sediment collection chamber.

In the centre of the cleaning pit above the separator is a porous concrete filter. The composition of the filter prevents the passage of fine material as water is forced up through the filter by hydrodynamic action. During this process, the majority of the dissolved heavy metals are precipitated or retained by adsorption. Filters can be manufactured to treat particular pollutant situations. Since the filter remains under water after a rain event, retained particles tend to detach themselves from the bottom of the filter and sink into the sediment collection chamber. By not allowing the filter to dry out, particles are prevented from accumulating on the underside of the filter. However, if accumulation does occur, the filter may be cleaned from the top by high pressure flushing. In the event of complete clogging, the filter can be replaced. To allow easy removal from the pit, the filter cartridge is made in two sections. The service life of a filter in regular use should be between 5 and 10 years. The sediment collection chamber should be sized to allow at least two years of use before emptying.

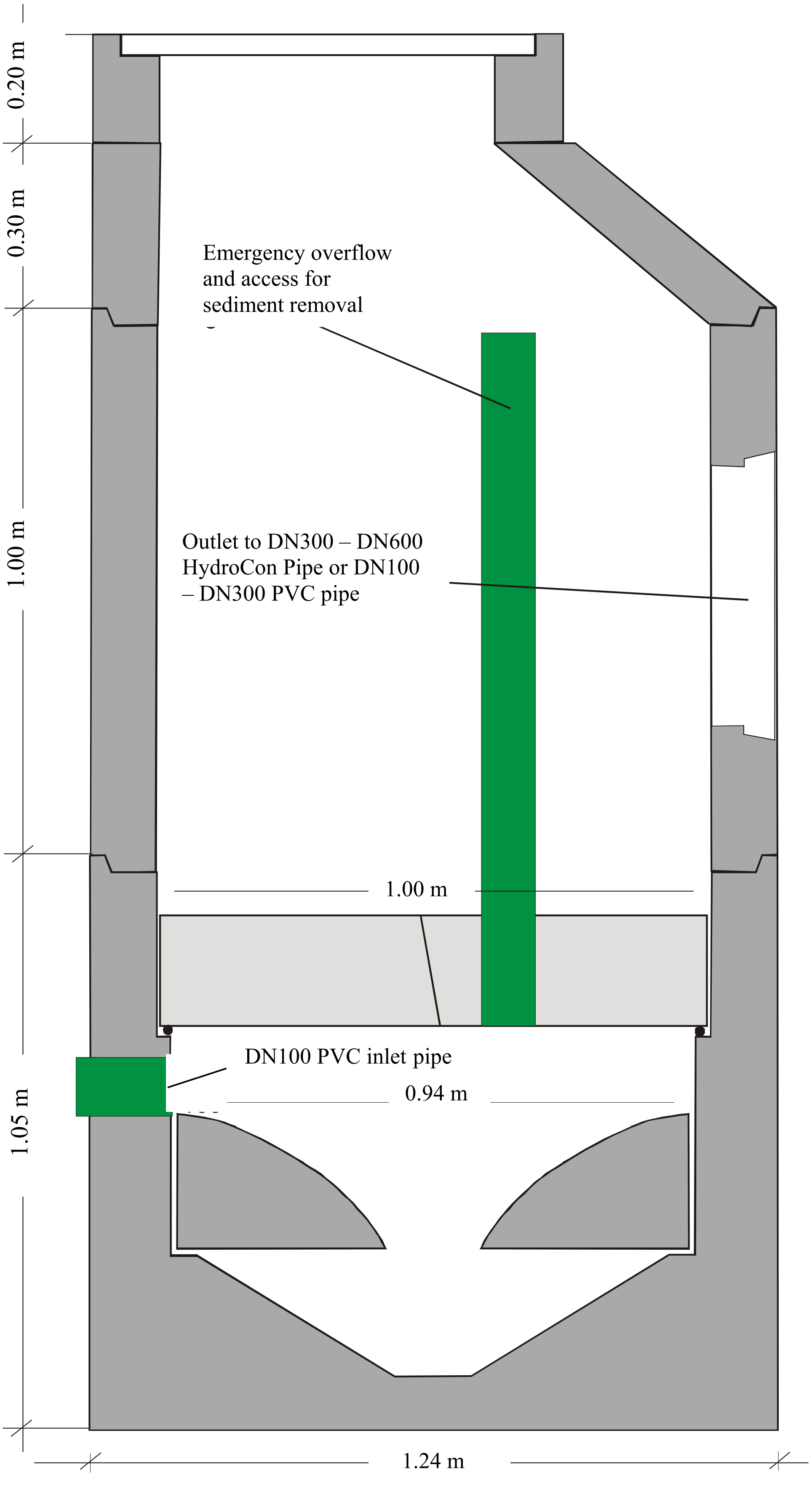

Illustration 1: Structure and dimensions of the DN1000 ecoStorm plus

3. Methodology

To determine the cleaning performance of the ecoStorm plus filter pit, an artificial or synthetic rainfall runoff was prepared from surface runoff and sludge from a concrete plant and other pollutants. The mixture was then pumped into a 1:10 scale model of the ecoStorm plus filter pit. The model consisted of the lower section of the pit, containing a cyclone sediment separator and a 16 cm high porous concrete filter. The concentrations of pollutants, suspended solids, pH and electrical conductivity values were determined before and after filtration.

3.1 Rainfall Runoff

Little is known at the present time about the composition of rainfall runoff from industrially and commercially used surfaces. This is partly because of the many different types of uses and the wide variety of pollutants being discharged. Furthermore, analysis of rainfall runoff from one industrial production site may not be readily transferable to other production sites.

Concrete plants are mainly involved in the manufacture, transportation and storage of cement based building materials. In addition to aggregates and sands, which are generally considered inert, the main materials used at such plants are cement, water and a range of chemical additives. Abrasions and hydrocarbon leaks from machinery and vehicles at the plant will also release heavy metals into the local environment.

In order to copy as accurately as possible the spectrum of pollutants likely to be present in the rainfall runoff, a laboratory sample should include sediment from all plant surfaces exposed to rainfall runoff. In this way, most materials likely to be present will be captured with the exception of those mineral oils whose composition changes over time. To take such changes into account, additional mineral oils should be added when preparing synthetic rain runoff.

For the purpose of this investigation, sludge samples were taken from the sink traps of a concrete products manufacturer in Ludwigshafen, Germany and made up as a synthetic rainfall runoff. As there is no information available about what concentrations of solids can be expected in the rainfall runoff from concrete production sites, results from other industrial surfaces and traffic areas were examined and an annual average value of approximately 100 mg/l taken as a benchmark. This compares with a level in rainfall of about 12 mg/l, 30 mg/l to 50 mg/l in rainfall runoff from roof areas, and up to 150 mg/l in runoff from traffic surfaces subject to heavy abrasion during winter.

3.2 Laboratory Testing

Tests were carried out using a 1:10 scale model of the ecoStorm plus filter pit. The lower part of the pit was represented using a plexiglass tube, as shown in Illustration 2. The cyclone sediment separator insert was made of concrete, the same material as for a full size ecoStorm plus filter pit. A porous concrete filter was placed above the sediment separator. The filter had a diameter of 10 cm and a height of 16 cm - equivalent to the height of a real filter, as filtration is dependant essentially on the height of the filter.

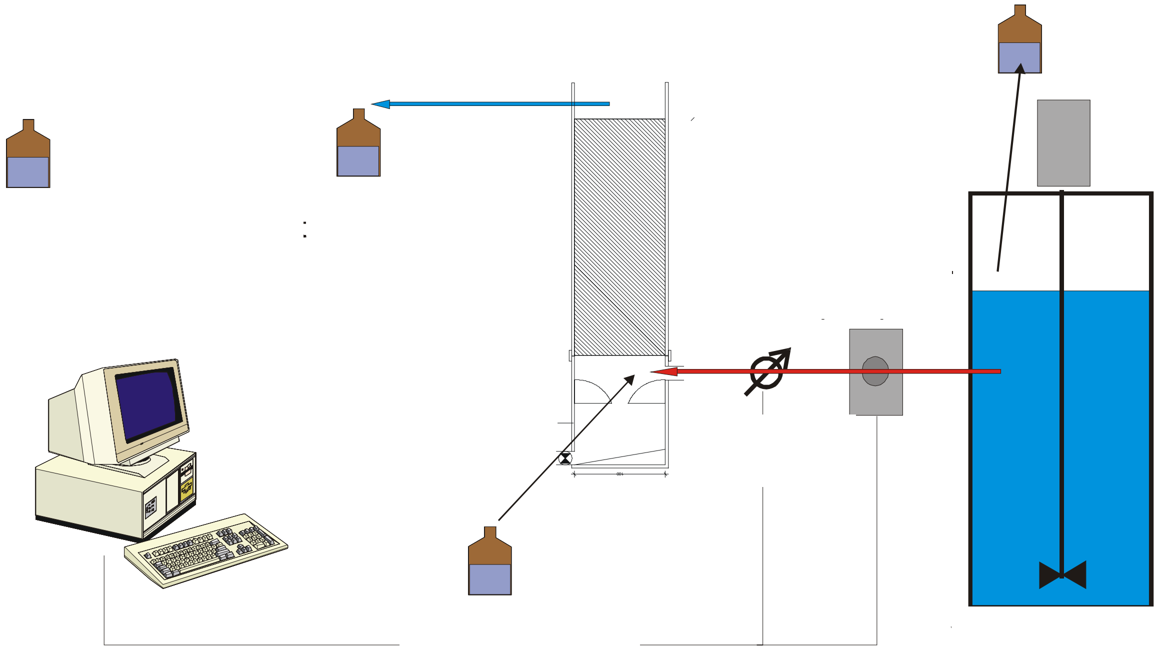

Illustration 2: Schematic Approach to Laboratory Testing

The synthetic rainfall runoff was homogenized in a 10 litre container with a 1000 rpm agitator (see Illustrations 3 and 4) to ensure an even distribution of pollutants. From there the mixture was pumped into the model pit with an adjustable hose pump. The flow rate was adjusted to 400 ml/minute, which corresponds to a rainfall of 13 l/(sxha) based on a maximum connected surface to the system of 500 m^2 per DN1000 pit. The model pit was therefore subjected to a medium to strong rainfall event. In comparison, frequent and continuous rainfall in rural Germany is between 3 l/(sxha) and 6 l/(sxha), with strong showers producing rainfall between 15 l/(sxha) and 30 l/(sxha). The latter intensities occur in Germany on average around 10 times per year. More severe rain events are very rare, and are not considered relevant in determining the efficiency of ecoStorm plus filters.

Illustration 3: Laboratory testing

Illustration 4: Synthetic mixture and agitator

Testing was designed to simulate a normal pit servicing period of two years. With an average annual rainfall in Germany of 800 mm, approximately 700 mm will be runoff and 100 mm will be lost in surface evaporation. 700 mm of runoff is equivalent to 350 m^3 of water per year (or 700 m^3 over two years). As the laboratory filter only had a diameter of 10 cm, compared with a normal filter diameter of approximately 100 cm, the quantity of synthetic rainfall runoff needed to be reduced to the equivalent of 3.5 m^3 (or 7 m^3 over two years). Since this quantity of water could only pass through the filter over a relatively long period of time, the concentration of the pollutants in the synthetic rainfall runoff was increased by a factor of 50. To maintain the same yearly rainfall equivalent, the quantity of water in the laboratory test was correspondingly reduced to 140 l. The filter was intermittently supplied with synthetic rainfall runoff, with 12 simulated rain events (of 5.8 l each) being performed over two days. Between events, supply was turned off for 30 minutes, so that the filter could regenerate. This regeneration time is however relatively short compared with the regeneration time under natural conditions, and does not fully allow for the time required for chemical reaction. It was recognised that, not only would results from laboratory testing be underestimated, but that due to the extremely high load on the laboratory model, results might more realistically correspond to a timeframe of 4 to 6 years.

After the first six simulated rain events, the model pit was taken apart and the sediment collection chamber emptied. This was necessary because the model had been designed for analysing rainfall runoff from roof areas and thus for a smaller accumulation of solids. In an operational setting, emptying would only be necessary after a minimum period of two years.

3.3 Analysis Methodology

The following indicates the analysis methods used in this appraisal. As these methods follow procedures set out in the respective DIN standards, detailed description is not provided.

Overall analysis was undertaken in accordance with DIN 38409-2. Heavy metals were analysed as total contents after acid testing in accordance with DIN EN ISO

11885. The determination of mineral oils was undertaken in accordance with DIN EN ISO 9377-2.

4. Results

Results of investigations are presented by specific analyte. pH values and electrical conductivity are initially discussed followed by heavy metals and mineral oil hydrocarbons.

4.1 pH value and electrical conductivity

pH and electrical conductivity identify the particular processes at work during filtration. pH values and electrical conductivities during the entire test period are represented in Illustration 5. The pH value of the synthetic rainfall runoff is stable between 7.6 and 7.8. As expected, the basic components in the sludge from concrete plant surfaces raise the pH value in the rainfall runoff to between 7 and 8. After filtration, the pH values are between 8.6 and 10.2. pH values of the first rainfall simulation on the first day (1) and the first simulation on the second day (7) are 9.5 and 10.2 respectively. The higher latter value is due to the water having a longer retention time in the filter. This can be related to the small quantity of water used in the tests, which were performed with superelevated concentrations in reduced time. In reality, the pH value after filtration will be between 8.5 and 9.0 (as also determined in the tests).

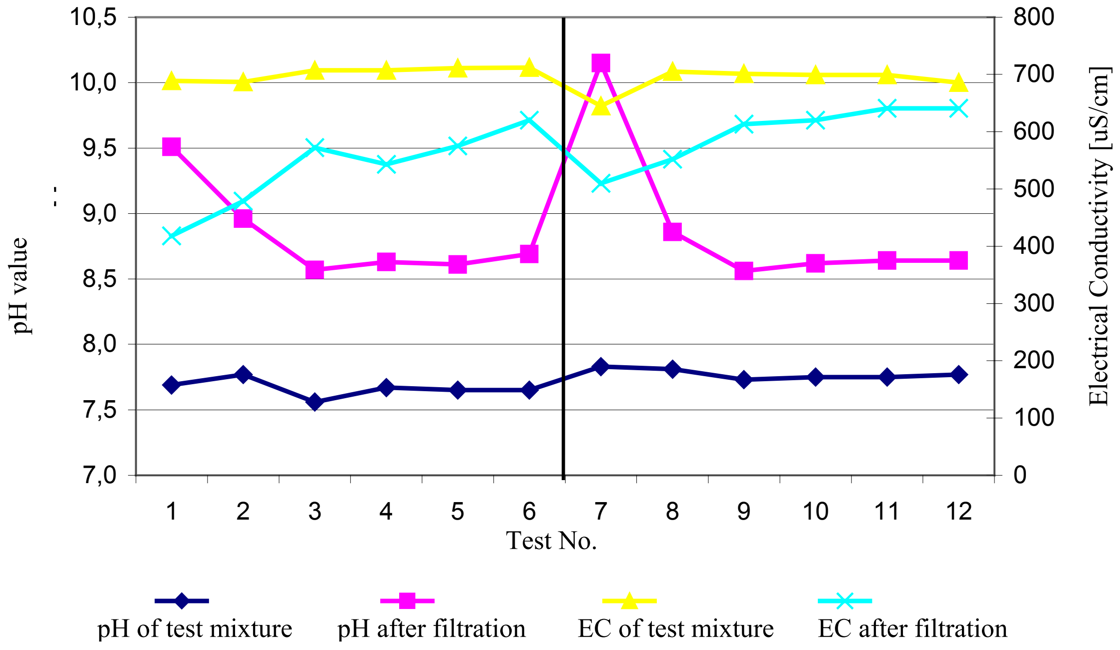

Illustration 5: pH values and electrical conductivities before and after filtration over test period

The rise in pH value of about one level can be related to precipitation processes taking place in the filter. As a result of these processes, dissolved heavy metals are captured and immobilized. A rise in pH value and metallic chemical reaction are the most important processes taking place in the filter.

The process of electrical conductivity is also represented in Illustration 5. The synthetic rainfall runoff shows an electrical conductivity of approximately 700 uS/cm. At the beginning of the tests, the electrical conductivity after filtration was 400 uS/cm, while towards the end it rose to approximately 650 uS/cm. The reduction in electrical conductivity suggests that ions are being retained in the filter. While it is apparent that the filter removes certain ions from rainfall runoff, it is not possible to explain at this stage the precise nature of the ion exchange processes taking place.

4.2 Retention of solids

Retention of solids is of crucial importance to the ecoStorm plus system because the passage of sediments can clog subsequent components of the treatment system. Retention is also important since most pollutants in rainfall runoff bind with sediment particles. Thus, by capturing sediments, the transport of pollutants is reduced. To measure the sediment retention effect of the ecoStorm plus system on the level of solids, readings were taken both before and after filtration.

Illustration 6 shows the sediment separating effect of the cyclone at the beginning of the tests. The particles fall through the opening in the centre of the cyclone and settle on the bottom of the sediment collection chamber. Of particular note is the stillness of the water in the chamber. Even with strong rain events, once sediments are in the collection chamber they remain in a stable and immobilised state. This is the major advantage of the ecoStorm plus cyclone pit over conventional sedimentation pits.

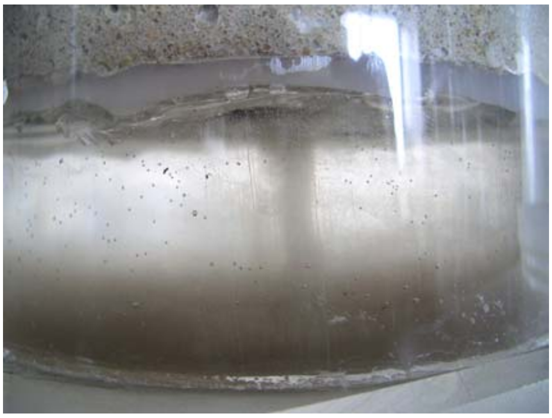

Illustration 6: Cyclone Sediment Separator

The sediment deposit after two rainfall runoff simulations is shown in Illustration 7. In an operational situation, the sediment can be easily removed by suction from the collection chamber.

Illustration 7: Sediment in collection chamber after two simulations

Solids levels before and after filtration are shown in Illustration 8. Solids in samples of synthetic rainfall runoff taken from the inlet measured on average 4983 mg/l. Since the concentration is equivalent to 50 times the level in actual rainfall runoff, the value is very realistic. Solids levels in samples taken after filtration showed progressive increases in filter efficiency. At the beginning of the tests, the solids level was 247 mg/l, corresponding to 95 % removal efficiency. During the tests, the effectiveness of the filter rose due to the build up of sediment on the underside of the filter. At the end of the tests, the solids level had fallen to 89 mg/l, giving an efficiency of 98%. The overall efficiency of the system over the time condensed simulated two year period was 96%.

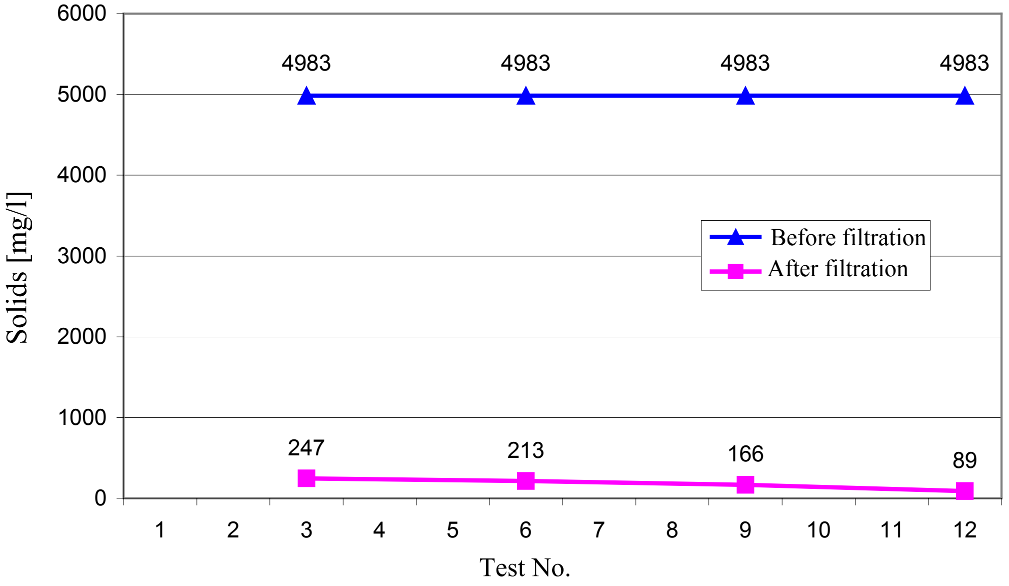

Illustration 8: Sediment levels before and after filtration

4.3 Retention of heavy metals

In addition to solids, heavy metals are usually the most common pollutants in rainfall runoff. Concentrations of heavy metals in the tested water were relatively high because of the high concentrations in the synthetic rainfall runoff. Before filtration, lead readings were 0.13 mg/l, cadmium 0.002 mg/l, copper 1.23 mg/l and zinc 1.74 mg/l. As expected, there is no danger to soil and water from lead and cadmium, when the respective concentrations are converted to actual runoff readings. Copper and zinc, however, were present in higher concentrations. After filtration, copper and zinc concentrations were well below those in the untreated synthetic rainfall runoff. Cadmium did not show up in any of the samples. Lead concentrations in all samples were below 0.05 mg/l. Copper readings were around 0.5 mg/l and for zinc between 0.2 and 0.4 mg/l. The removal efficiency was 66% for lead, up to 57% for copper, and up to 80% for zinc.

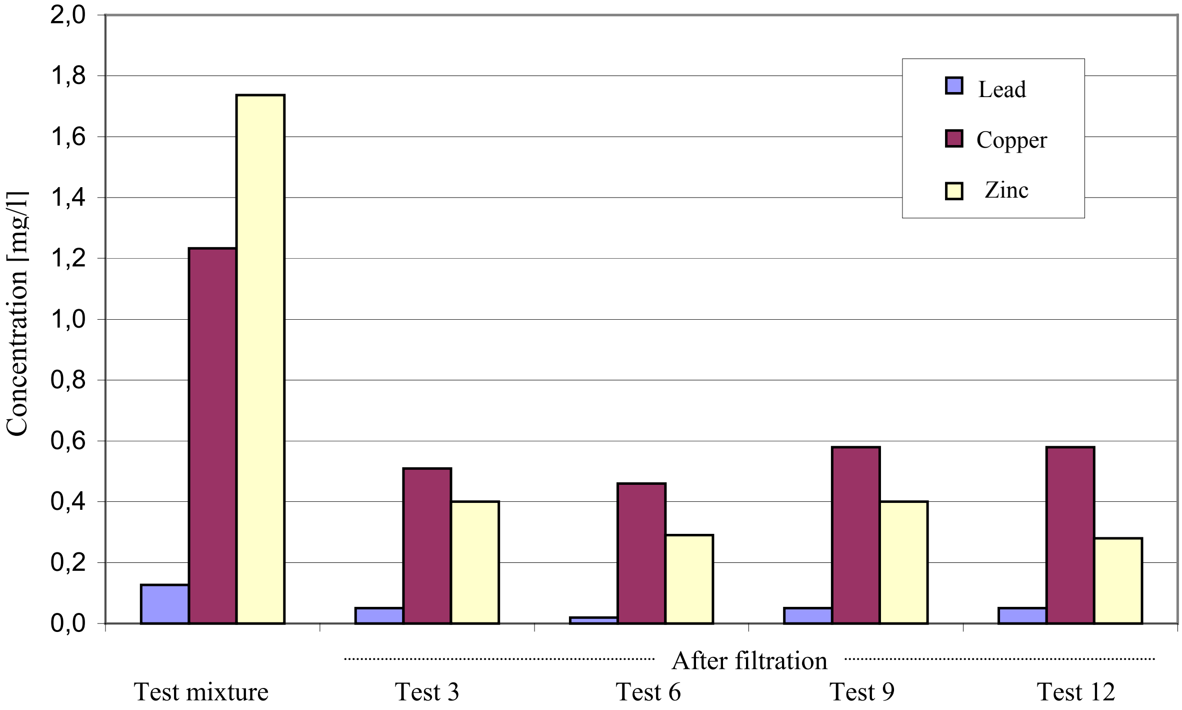

Illustration 9: Lead, copper and zinc levels before and after filtration

The filters were subjected to 12 simulated rain events over 2 days. Under natural conditions, retention can be expected to be much higher than in the laboratory since the larger number of rain events and longer periods between events allow greater filter regeneration. The quick-motion apparatus of a laboratory test is not able to simulate the regeneration process.

4.4 Retention of mineral oils

To enable investigation of the retention of mineral oils in the system, it was necessary to ensure a sufficiently high level of hydrocarbons in the synthetic rain runoff over the test period. Diesel fuel was therefore added to the synthetic runoff. Diesel has a lower viscosity than engine oils, causing it to be more easily transported in rainfall runoff. At present, runoff from high volume service stations has at least 1 mg/l of mineral oil. Assuming that concentrations are likely to be higher at a concrete plant, a value of 5 mg/l was used in the appraisal (requiring 250 mg/l of diesel to be added for the purposes of the model).

Illustration 10 shows the concentrations of mineral oil hydrocarbons before and after filtration. Over the 12 tests, concentrations after filtration were reduced from 24 mg/l to 8 mg/l. The porous concrete filter was entirely responsible for this reduction as there was no other oil barrier fitted. Oil floating on the surface after filtration was washed directly into a sampling bottle. Removal efficiency of the system for mineral oils is thus 94%. With more viscous engine oils, efficiency can be expected to be even higher.

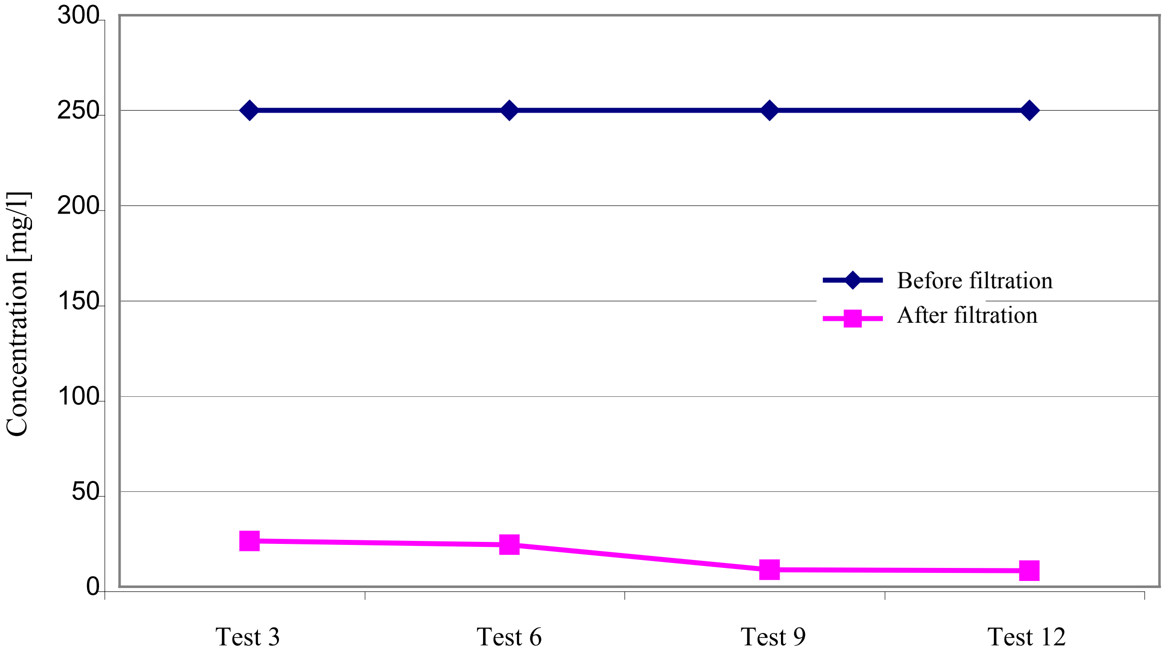

Illustration 10: Retention of hydrocarbons in the ecoStorm plus filter pit

4.5 Calculated concentrations compared with goal values

As factorised concentrations in the synthetic rainfall runoff were of course very much higher than would occur in practice, it is necessary to normalise concentrations for expected removal efficiency. The normalisation procedure is problematic since it presupposes a linear retention process over the particular concentration range, which might not necessarily be the case. Since the model was operated under artificial laboratory conditions, which included absence of adequate filter regeneration phases, the results could give lower retention values than might occur in practice. The method can be used with caution for forecasting the treatment performance of the system, and in all probability will tend to underestimate retention levels.

Table 1: Limit values and post filtration test values

Substance	Unit	State Water Commission [1]	Drinking Water Regulation [2]	Soil Protection Law [3]	ecoStorm plus filter [4]
Sum parameter					
Electrical Conductivity	uS/cm	-	2500	-	< 700
pH value		-	6.5 – 9.5	-	8.5 – 9.5 (10.0)
Heavy metals					
Cadmium Cd	μg/l	1.0	5.0	5.0	< 1
Zinc Zn	μg/l	500	-	500	< 10
Copper Cu	μg/l	20	2000	50	< 15
Lead Pb	μg/l	50	10	25	< 1
Organic sum parameter					
MKW	mg/l	-	-	0.2	0.2 (0.4)

[1] State Water Commission (1998) – limits for the protection of surface and potable water
[2] Drinking Water Regulation (2001) - thresholds
[3] Federal Soil Protection Regulation (1999) - test values of efficiency path for soil and groundwater
[4] Calculated post filtration test values

Table 1 gives maximum allowable analyte levels in Germany under LAWA (State Water Commission) water use protection targets, the Drinking Water Regulation and the Federal Soil Protection Law. The table also gives calculated effluent concentrations from the laboratory tests outlined in this report.

Although limits for electrical conductivity and pH are only specified in the Drinking Water Regulation, allowable limits for both parameters would be met if the ecoStorm plus system were used to treat rainfall runoff from a concrete plant. Although a pH value of 10.2 was obtained in one test result, experience with the system under operational conditions indicates that the pH value would be no higher than 9.5.

The test results for the filter pit satisfy heavy metal limits under all laws and regulations. This applies even under the strict LAWA limit for copper of only 25 mg/l. With MKW, while the Federal Soil Protection Law's 0.2 mg/l limit is exceeded at the beginning of the tests, the limit is reached midway through the tests. Given the superelevated concentrations and low viscose diesel oil used in the laboratory tests, substantially higher retention levels are likely under normal operating conditions. If still higher concentrations were to be used, an immersion tube inserted into the outlet of the pit to hold back the floating components of oils and fuels should increase the overall removal efficiency for mineral oil hydrocarbons to over 99%.

5. Evaluation and recommendations

From test results and outcomes described in this report, it is evident that the ecoStorm plus filter pit is able to remove all relevant pollutants to a sufficient degree from rainfall runoff to enable infiltration or surface discharge of effluent.

pH values in the effluent lie between 8.5 and 9.5 and thus in a range suitable for infiltration or surface discharge. With infiltration, the basic pH value will help stabilise any heavy metals existing in the soil.

Efficiency of the system for retention of solids was between 95% and 98% in the tests. Since rain events in Germany would yield less rainfall than the relatively high rainfall simulations conducted in the tests, removal efficiency for solids might in practice exceed these values.

In the laboratory tests, removal efficiency rates for heavy metals ranged from 57% to 80%. Expected concentrations in discharges after filtration are well below the limits required under German Federal soil protection legislation and drinking water regulations. Regeneration of the filter between rain events increases retention rates, as shown by measurements taken from ecoStorm plus filter pits installed in Munich. Test retention rates for mineral oil hydrocarbons had an overall efficiency of 94%, without any additional oil barriers. A porous concrete filter is sufficient for retention of normally expected concentrations of mineral oil hydrocarbons in rainfall rain runoff.

In conclusion, if a ecoStorm plus filter pit were to be installed at a concrete plant to treat rainfall runoff, all relevant pollutants would be satisfactorily removed to allow surface discharge or infiltration directly into the ground.

6. References

ATV (2000): Working Paper A 138: Planning, construction and operation of systems for infiltration of rainwater. GFA Society for the Promotion of Sewage Engineering e.V.; Hennef

DIN 38409-2, Edition:1987-03: German standard method for water, waste water and mud investigation; Summary characteristics of effect and material (Group H); Determination of filterable materials and ignition residue (H 2)

DIN EN ISO 11885, Edition:1998-04: Water condition - Determination of 33 elements through inductively coupled plasma atomic emission spectrometry (ISO 11885:1996); German version EN ISO 11885:1997

DIN EN ISO 9377-2, Edition:2001-07: Water condition – Determination of the hydrocarbon index - Part 2: Procedure for solvent extraction and gas chromatography (ISO 9377-2:2000); German version EN ISO 9377-2:2000