Passive Filter – Sustainable BMP for Permanent Stormwater Treatment of Heavy Metals, Nutrients, Hydrocarbons and Sediment

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ABSTRACT
Passive filtration provides a sustainable alternative to classical drainage concepts for source control of hydrocarbons, heavy metals and nutrients that endanger our water bodies.

In urban areas with high building density, traditional drainage concepts like wetlands are not available and the concept of decentralized treatment facilities that can be housed in catch basin structures are a viable option for treatment of pollutants.

A European and US study is underway to determine the parameters of sustainable on-site retention and infiltration. The European study progressed in three stages. In the first stage the catch basin (hydrodynamic separator and filter housing) was developed and investigated on a laboratory scale, including the hydraulic behavior and the retention of the sediments. Secondly, filters of concrete were assessed in laboratory scale catch basins. The filters were charged with an artificial runoff, which was spiked with pollutants. Concentrations in the influent and the effluent were measured and the design details of the catch basin and its concrete filters were optimized. In the third step field investigations of the catch basin treatment facility were carried out to show the performance of the system while under real conditions.

The results of this sustainable alternative in European data showed, depending on the water runoff characteristics, more than 90% total suspended solids removal, between 40% and 95% reduction in heavy metals (zinc, cadmium, copper and lead), greater than 90% removal of mineral oils and more than 60% reduction in phosphorous.

In a cooperative effort, the U.S. study has been commissioned for the Ramsey-Washington Metro Watershed District (RWMWD) in Twin Cities, MN with the support of the Ramsey County Public Works, Hydro International, Royal Environmental, Water Tectonics and Barr Engineering will design, construct, study, and document the effectiveness of four different proprietary BMP configurations as treatment practices for addressing non-point source pollution. The results of this project will be used to determine the efficacy and potential for widespread application throughout the upper Midwest. In addition, performance data required in Washington State has been conducted by Water Tectonics and has shown similar removal rates to the European data.

Implementation of a decentralized catch basin treatment facility can effectively remove pollutants from urban stormwater run-off. Benefits include a small footprint, easy maintenance, and lower filter cost, based on a calculated filter life between 3 and 10 years.

CHANGING U.S. REGULATORY CLIMATE

A stricter regulatory climate is on the rise within the U.S. with regards to non-point source pollution. The NPDES program covers industrial activities, construction activities and local municipalities with stormwater conveyance systems. The EPA has delegated NPDES program responsibilities to State agencies in 48 states. This last year has brought significant changes to both the construction and industrial permits, specifically, to the lowering of the acceptable levels of pollutant loading to our natural water bodies. Municipalities are also being held to more specific discharge limits and are in turn upgrading design specifications for new and retro-fit projects to implement more effective stormwater flow control and water quality treatment. Currently, the Regional Administrators of EPA Regions 1, 2, 3, 5, 6, 9 and 10 are proposing a re-issuance of EPA's NPDES Stormwater Multi-Sector General Permit (MSGP). This general permit, MSGP 2006, when finalized, will replace the MSGP 2000, which was issued on October 30, 2000 (65 FR 64746), and expired on October 30, 2005.

Table 1 includes all of the pollutants for which the proposed MSGP 2006 specifies benchmarks. Where a benchmark has changed, it has been for one of the following reasons:

- The values for 9 benchmarks (arsenic, cadmium, copper, cyanide, lead, mercury, nickel, selenium, and silver) have been revised (e.g., switching from an MDL to an ambient water quality criterion, or updated to reflect a revised WQ criterion).
- The values for 4 benchmarks (antimony, lead, magnesium, and zinc) have been rounded to two significant figures.

The existing turbidity benchmark, 5 NTU above background, requires the permittee to monitor both the discharge and the receiving stream. The proposed new benchmark (50 NTU) requires the permittee to monitor only the discharge.

Table 1. Comparison the MSGP 2000 and MSGP 2006 benchmark values and the source of those values.

Comparing Benchmark Monitoring Pollutants Sources for 2000 and 2006 MSGP					
Pollutant	2000 MSGP Benchmark	2000 MSGP Source	2006 MSGP Proposed Benchmark	2006 MSGP Source	Different basis?
Ammonia*	19 mg/L	10	19 mg/L	1	No
Biochemical Oxygen Demand (5 day)	30 mg/L	4	30 mg/L	4	No
Chemical Oxygen Demand	120 mg/L	5	120 mg/L	5	No
Total Suspended Solids	100 mg/L	7	100 mg/L	7	No
Turbidity	5 NTU above	13	50 NTU	9	Yes

Table 1 (contd.). Comparison the MSGP 2000 and MSGP 2006 benchmark values and the source of those values.

Comparing Benchmark Monitoring Pollutants Sources for 2000 and 2006 MSGP					
Pollutant	**2000 MSGP Benchmark**	**2000 MSGP Source**	**2006 MSGP Proposed Benchmark**	**2006 MSGP Source**	**Different basis?**
	background				
Nitrate + Nitrite Nitrogen	0.68 mg/L	7	0.68 mg/L	7	No
Total Phosphorus	2.0 mg/L	6	2.0 mg/L	6	No
pH	6.0 - 9.0 s.u.	4	6.0 - 9.0 s.u.	4	No
Aluminum, Total (pH 6.5 - 9)	0.75 mg/L	10	0.75 mg/L	1	No
Antimony, Total	0.636 mg/L	8	0.64 mg/L	12	Yes
Arsenic, Total	0.16854 mg/L	8	0.15 mg/L	3	Yes
Beryllium, Total	0.13 mg/L	2	0.13 mg/L	2	No
Cadmium, Total†	0.0159 mg/L	8	0.0021 mg/L	1	Yes
Chromium, Total†	N/A	N/A	1.8 mg/L	1	Yes; added as a new benchmark in 2006 MSGP
Copper, Total*†	0.0636 mg/L	8	0.014 mg/L	1	Yes
Cyanide	0.0636 mg/L	8	0.022 mg/L	1	Yes
Iron, Total	1.0 mg/L	11	1.0 mg/L	3	No
Lead, Total*†	0.0816 mg/L	10	0.082 mg/L	1	No
Magnesium, Total	0.0636 mg/L	8	0.064 mg/L	8	No
Mercury, Total	0.0024 mg/L	10	0.0014 mg/L	1	criteria updated
Nickel, Total†	1.417 mg/L	10	0.47 mg/L	1	criteria updated
Phenols, Total	N/A	N/A	0.016 mg/L	8	Yes; added as a new benchmark in 2006 MSGP
Selenium, Total*	0.2385 mg/L	8	0.005 mg/L	3	Yes
Silver, Total*†	0.0318 mg/L	8	0.0038 mg/L	1	Yes
Zinc, Total†	0.117 mg/L	10	0.12 mg/L	1	No; criteria updated

In most cases, benchmarks have not been significantly revised since the 1995 MSGP. However, six of the benchmarks now have new values based on EPA water quality criteria, which are lower than the previous values. These are cadmium, copper, cyanide, selenium, silver, and nickel. For the first five of these, the values have been changed from 3.18 times the MDL for a particular analytical method, to ambient water quality criteria. In each case, EPA has identified one or more alternate methods with lower detection limits.

In summary, the EPA has water quality goals, which are passed down to local municipalities, industrial users and construction through permits. This is one of several compelling events that are driving a change in the design of permanent water conveyance and treatment facilities.

STUDY OBJECTIVES

The main objective of the US study is to validate the European performance study under domestic conditions and regulatory requirements. Data from the Ramsey-Washington Metro Watershed District (RWMWD) in Twin Cities, MN and other beta sites in Washington State will be used the final analysis. Goals of the study will be to achieve both high pollution retention capacity and a satisfactory flow-rate. In addition, solid and dissolved pollutants need to be removed from runoff by sedimentation, filtration, adsorption and chemical precipitation. Lastly, the study will investigate the mobility of heavy metals and hydrocarbons and its impact on soil and groundwater.

PROBLEM IDENTIFICATION

Four types of drained surfaces in urban areas must be differentiated for a treatment system. These are: semi permeable surfaces (grass areas in gardens, parks and public space, paved areas), roofs, traffic areas and industrial / commercial sites. The first type of surface is not of major concern, because the water normally infiltrates directly into the ground and pollutant loads are usually small. Roofs and traffic areas show higher loads of pollutants and the concentration of specific substances varies. Industrial sites show highest concentrations in runoff, but these are not easy to predict and tend to require individual measurement.

Wet detention basins have resulted in significant progress toward improving the water quality of the runoff from urbanizing watersheds and some re-developed areas. However, detention basins can cause increases in water temperature and require significant space that is not typically available in fully developed watersheds. More importantly, in metropolitan areas smaller, developed sub-watershed areas drain directly to the receiving waters untreated.

The Phalen Chain of Lakes watershed in the Ramsey-Washington Metro Watershed District (RWMWD), along with many other major drainage areas in the RWMWD and throughout the Twin City metropolitan area is such an example of this problem. Past monitoring and modeling indicates that the Owasso Basin water quality treatment is not currently meeting the RWMWD water quality goals and that the flow from several smaller untreated drainage areas is short-circuiting the basin.

Ideally, infiltration practices can be implemented as part of retrofit projects involving lower density residential developments. But these practices are difficult to implement in higher density developments or drainage areas with less permeable soils. Drainage systems within existing, higher density developments can be retrofitted with grit chambers, catch basin sumps or other proprietary structures, but these devices can be expensive and their treatment effectiveness has not been well documented or evaluated in a consistent manner. In-situ studies that have been done on grit chambers and catch basin sumps have shown that these devices have limited ability to remove soluble pollutants and finer particulates, regardless of maintenance activities. However, the desire for higher density development within metropolitan areas and better water quality treatment for areas draining directly to sensitive waters has fueled significant growth in the proprietary BMP industry in the last decade. As a result, several state agencies and water management organizations have attempted to better evaluate the water quality treatment effectiveness of proprietary BMPs and standardize monitoring protocols.

POLLUTANTS IN RUNOFF

Stormwater contains pollutants that can endanger soil and groundwater in the long term (Remmler & Hütter 2001). Pollutant concentrations and loads have been measured in many investigation projects over recent years. Some substances cause problems in infiltration systems, notably:

- dissolved metals from metal roofs (Odnevall-Wallinder et al. 2001);
- mineral oils and polycyclic aromatic hydrocarbons from traffic areas; and
- hydrocarbons from other sources such as asphalts and bituminous roof coverings.

Concentrations of these substances vary with location, land use and material of the drained surface. While concentrations in rain are usually low, levels increase when runoff flows off roofs and traffic areas. Copper (Cu) or zinc roofs (Zn) and metal drainage components, e.g. gutters and drainpipes, emit very high concentrations of these metals. Very high concentrations of cadmium (Cd), lead (Pb), PAH (polycyclic aromatic hydrocarbons (PAH) and mineral oil type hydrocarbons (MOTH) have been found in traffic areas (Drapper et al. 2000). Concentrations progressively increase in line with traffic intensities. In Coldewey and Geiger (2004) concentrations were evaluated from over 300 studies with more than 1300 event mean concentrations. The European literature data was tested for plausibility (value levels, quality of documentation). Median concentrations of selected heavy metals and hydrocarbons cited in the literature are shown in Table 2. The development of filters in the current study was based on these concentrations.

Table 2. Median concentrations in runoff of heavy metals and hydrocarbons from different drained surfaces

Drained surface		Unsealed surfaces, garden, grassland	Roof, green roof	Roof, without metal elements	Roof, with zinc drains	Roof, zinc	Roof, copper	Traffic, pedestrian lane, yard	Traffic, car park	Traffic, residential street
Heavy metals										
Cd	µg/l	0.7	0.1	0.8	0.8	1.0	0.8	0.8	1.2	1.6
Zn	µg/l	80	468	370	1851	6000	370	585	400	400
Cu	µg/l	11	58	153	153	153	2600	23	80	86
Pb	µg/l	9	6	69	69	69	69	107	137	137
Hydrocarbons										
PAH	µg/l	0.39	-	0.44	0.44	0.44	0.44	1.00	3.50	4.50
MOTH	mg/l	0.38	-	0.70	0.70	0.70	0.70	0.16	0.16	0.16

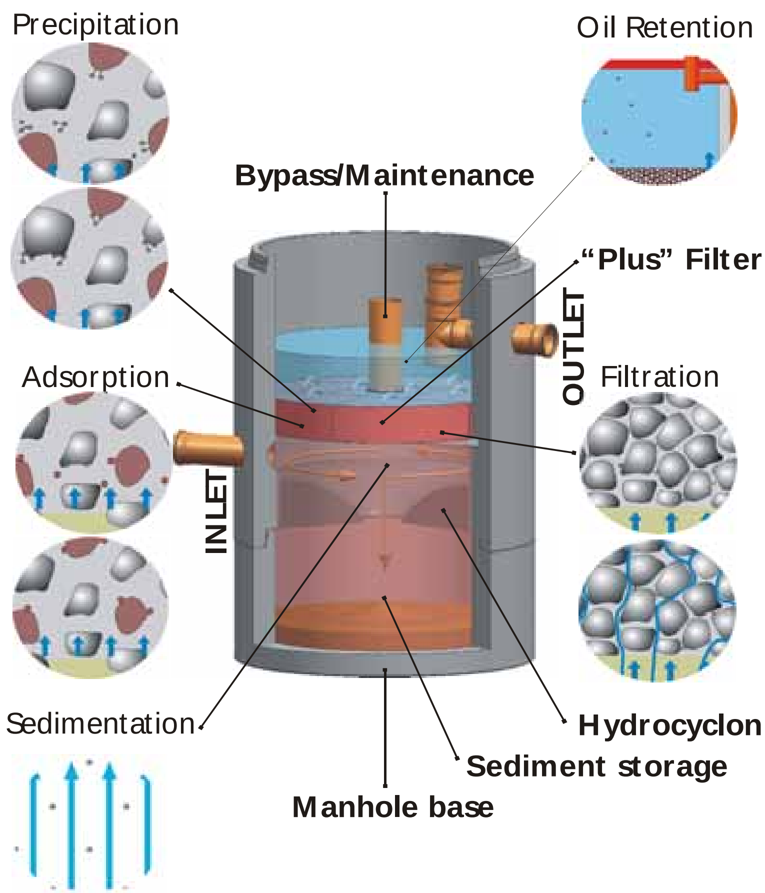
PAH: polycyclic aromatic hydrocarbons
MOTH: mineral oil type hydrocarbons

PASSIVE FILTER DESIGN

The new stormwater treatment system, which is the subject of this study, provides three levels of treatment. The system is located underground and consists of specially designed concrete vaults (Figure 1). Primary and some secondary treatment of stormwater occur in the vault by means of sedimentation, filtration, adsorption and chemical precipitation. The initial removal process is undertaken using a hydrodynamic separator and a vertically charged multistage concrete filter. After initial treatment in the concrete vault, stormwater upflows through a porous concrete filter.

The concrete buffers the pH level of the stormwater, which otherwise is typically acidic. Heavy metals are removed by chemical precipitation as stormwater flows through the porous concrete filter. Removal of metals is improved by addition of specific hydroxides to the concrete. Sediments and associated pollutants, such as heavy metals, can be removed by back flushing and extracted from the special concrete vaults. Tertiary treatment of stormwater is undertaken both within the structure and the surrounding media as biofilms develop and digest organics and nutrients. The combined effect of this treatment train ensures very high retention of pollutants and high water quality for infiltration into the ground, discharge into waterways or storage for reuse.

Figure 1. The stormwater pollution passive filter design



Concrete-based filters allow chemical precipitation as well as adsorption processes to take place. Such filters showed lower removal efficiencies in the beginning, but efficiency did not decrease as in the case of the GEH filter over the tested period. Thus, concrete-based filters can be assumed to have a longer operational life.

Following laboratory tests, the system was investigated in a real scaled facility. Performance of the system in infiltrating road runoff is presented in Table 3. Two years of operation were simulated in the facility with artificial runoff being used over a period of several weeks. Removal efficiency was found to be more than 96 % for lead (Pb) and copper (Cu) and 84 % for zinc (Zn).

Over 99 % of mineral oils (MOTH) were trapped with no concentrations able to be detected in effluent. The retention of total suspended solids (TSS) was greater than 99 %.

Table 3. Removal efficiency under near natural conditions

Parameter	Pb	Cu	Zn	MOTH	TSS
Removal Efficiency	96 %	99 %	84 %	99 %	99 %

CONCLUSIONS

The investigation results from the decentralized filter system show that pollution retention greater than 90 % can be achieved for most constituents. In particular, heavy metals and hydrocarbons can be removed from runoff even when runoff is generated from metal roofs, traffic areas or industrial sites. As pollution retention works by means of sedimentation, filtration, adsorption (ion exchange) and chemical precipitation, even dissolved pollutants can be removed by the passive filter. The use of different kinds of filters allows the system to treat runoff from a large range of drained surfaces. Pollutants will be trapped within the vault by the sedimentation chamber and filters and can be removed easily. In some cases, maintenance will only be required every 5 to 10 years. Long term studies on treating runoff from metal roofs and industrial areas have started, with initial results of performance expected to be available over the next few years.

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