Stormwater management in a catchbasin perspective – best practices or sustainable strategies?

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Abstract A strategy for sustainable stormwater management is needed. This study has focused on the relative importance of stormwater as a pollutant source in a catchbasin, if Best Management Practices (BMPs) result in pollutant removal or pollutant redistribution, and methods for screening of stormwater strategies. Stormwater is most likely an important pathway for pollutants in a catchbasin perspective. True pollutant removal can only be achieved if the pollutant sources are eliminated. Until that is reached, we should have the best possible control of the pollutant fluxes in the watershed. This study indicates that the search for a sustainable stormwater strategy could be easier to handle if different “screens” could be used. The Swedish environmental objectives, which try to encapsulate all aspects of sustainability, may be used as a foundation for a “sustainability screen”. By using this screen, the “unsustainable” features of different stormwater strategies could be pointed out. A “standards and legislation screen” will be based on the EU Water Framework Directive. As this study has shown, it is doubtful whether the conventional BMPs, such as stormwater ponds and infiltration facilities, produce a sufficient pollutant control.

Keywords BMP; EU Water Framework Directive; infiltration; pollution; pond; screening; sustainability; urban runoff

Introduction

For a long time, the interest in stormwater has been directed on how to drain away the precipitation as quickly as possible, often by leading it to the nearest recipient. Due to the complex mixture of different types of substances in urban runoff, storm water may have a detrimental effect on water, soil, vegetation, animals and microorganisms. This impact depends both on the properties of the storm water, such as the concentration of pollutants, volume, flow, and temperature, and on the properties of the receiving body.

A large number of stormwater facilities have been built up in cities and along highways as a result of the awareness of the environmental impacts caused by storm water pollution. These facilities, often called BMPs (Best Management Practices), will change the path of water and pollutants in the city. The main question, though, remains unanswered: Are these BMPs sustainable? What will happen to the heavy metals and the persistent organic pollutants? Or, more bluntly put: is it better to place the pollutants in the running water, in the soil or in the groundwater?

A strategy for sustainable stormwater management is needed. The proper framework for developing such a strategy is the catchbasin or the river basin. The water policy in Europe, as expressed in the EU Water Framework Directive, supports and requires this kind of planning. A sustainable strategy should consider not only the pollution aspects, but also use of natural resources, health and hygiene, total costs and socio-cultural aspects. This study has focused on the relative importance of stormwater as a pollutant source in a catchbasin, if Best Management Practices (BMPs) result in pollutant removal or pollutant redistribution, and methods for screening of stormwater strategies.
The relative importance of stormwater as a pollutant source in a catchbasin

Studies of heavy metal fluxes from technosphere to biosphere in Stockholm have shown that stormwater is a major pathway (Palm and Östlund, 1996; Lindström, 2001). For copper and lead in lake sediments in the Stockholm region, the urban influence dominated (Lindström, 2001). Cadmium and mercury were not correlated to land use parameters to the same extent.

Stormwater pollutants mass load calculations for three different catchbasins in Sweden are summarised in Table 1. The Emån watershed, situated in the southeast of Sweden, is approximately 4,500 km² and the average flow in the river is 30 m³/s. The area has 100,000 inhabitants living in 7 municipal regions. The stormwater pollutant load was calculated within the Emån river project during year 2000 (Tholén and Envall, 2000). The stormwater pollutant load has also been investigated in the Braån/Saxån watershed (368 km²) in the southernmost part of Sweden (Ekologgruppen, 1997). The Swedish road authority made an evaluation of the relative importance of road runoff on pollutant accumulation in Lake Aspen, situated in the vicinity of Stockholm and highway E4/E20 (Swedish National Road Administration, 1999). The catchbasin of Lake Aspen is 8.3 km², 88% of this area consists of forest and arable land.

Similar calculation procedures were used in all three catchbasins: calculation of impervious area by using map-analysis, definition of hydrological parameters (precipitation, evaporation, and runoff coefficients), and selection of standard values of stormwater pollutant concentrations. The standard concentrations were chosen based on local conditions and/or literature published by the Swedish Water and Wastewater Association (Malmqvist et al., 1994; Larm, 1994). Applied standard concentrations for Emån and Braån/Saxån are included in Table 1. Unfortunately, no calculations for PAH have been found in the reviewed literature.

As seen in Table 1, the results from the three watersheds indicate that stormwater is an important source for heavy metals (Cd, Cu, Pb, and Zn). Lead shows the highest degree of stormwater influence even though lead concentrations in stormwater have decreased during recent years due to the introduction of unleaded fuel in the late 1980s. For nutrient loads, especially nitrogen, other sources in the catchbasins dominate. The ratio of urban area to total catchment area is similar in the catchbasins of Emån and Braån/Saxån (0.2–0.4%). For Lake Aspen, urban runoff was responsible for 97–99% of the mass load of the heavy metals normally associated with stormwater. However, the applied standard concentrations of stormwater pollutants were not documented in the literature. The 3 km long stretch of highway E4/E20 with 50 000 vehicles/day that intersects the Lake Aspen catchbasin contributed with 4% of the surface runoff and 10–13% of the heavy metals.

Table 1  Stormwater pollutants mass loading estimates in three Swedish catchbasins

<table>
<thead>
<tr>
<th></th>
<th>Emån (kg/year)</th>
<th>Braån/Saxån (kg/year)</th>
<th>Lake Aspen (kg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tot-N</td>
<td>5,747</td>
<td>1983</td>
<td>–</td>
</tr>
<tr>
<td>Tot-P</td>
<td>910</td>
<td>397</td>
<td>–</td>
</tr>
<tr>
<td>Cd</td>
<td>–</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Cu</td>
<td>77</td>
<td>50</td>
<td>119</td>
</tr>
<tr>
<td>Pb</td>
<td>152</td>
<td>50</td>
<td>119</td>
</tr>
<tr>
<td>Zn</td>
<td>768</td>
<td>258</td>
<td>391</td>
</tr>
<tr>
<td>Total area</td>
<td>4,472 km²</td>
<td>368 km²</td>
<td>8.3 km²</td>
</tr>
<tr>
<td>Urban area</td>
<td>11 km² (0.2%)</td>
<td>1.6 km² (0.4%)</td>
<td>1.0 km² (12%)</td>
</tr>
</tbody>
</table>

1 Applied standard concentration (S.C.) of pollutant

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National Road Administration, 1999). It is notable that the load of pollutants from the comparatively small catchment of Lake Aspen is very high.

In most cases the stormwater quality is characterised in terms of concentrations (mg/l or µg/l) of different pollutants. Acute toxic effects may be correlated to the concentration of the pollutant but long-term effects, such as accumulation of pollutants in sediments and biota, are linked to the load, for example expressed as kg of pollutant per year emitted to the receiving water. If stormwater pollution should be compared with other pollutant sources, mass load is in many cases a more appropriate parameter to use than concentration. Long-term effects of a pollutant are also governed by the water quality in the recipient. Changes in pH, redox conditions and conductivity may for example increase the mobility and availability of heavy metals.

Mass loads of stormwater pollutants can only be measured accurately if sampling is continuous and flow-weighted but this sampling method is often very costly and time-consuming in a catchbasin perspective. Calculated mass loads, based on standard concentrations, can be used for targeting “hotspots” (i.e. stormwater outlets with high loads), which was done in the Emå river project (Tholén, 2000). However, one should keep in mind that the calculated loads are impaired by significant uncertainties.

Best Management Practices (BMPs) – pollutant removal or pollutant redistribution?

There are a number of different methods to avoid stormwater pollutants being transported to the recipients. These so called Best Management Practices (BMPs) may include source control, detention facilities, local disposal of stormwater (i.e. infiltration), wet ponds, wetlands, ditches, and swales. By using one, or several, of the BMPs, the fluxes of pollutants are changed. A pollutant that is transported directly to the receiving waters by separate stormwater pipes or ends up in the sewage sludge in the case of a combined pipe system, may instead accumulate in the sediment, soil, or organic material of the employed BMP structure. It is not within the scope of this article to fully describe all types of BMPs, but two of the most common structural BMPs will be discussed here, namely wet ponds and stormwater infiltration facilities.

The use of wet ponds has increased during the last 10 years and several more ponds are planned to be built, especially for road runoff treatment. Wet ponds act as pollutant traps, mostly for particle bound pollutants, and as peak flow reducers. These are probably the major reasons why wet ponds have become so popular. Furthermore, wet ponds have gained acceptance among landscape architects and citizens, who often look upon ponds as ecological and aesthetic objects in the urban environment. Pettersson et al. (1999) measured long-term pollutant removal in two stormwater ponds with specific pond areas of 40 and 240 m²/ha. The ponds trapped between 80% (low loaded pond) and 30% (high loaded pond) of zinc and copper in the influent (Table 2). The trapped pollutants most likely ended up in the pond sediment, which may contain up to 0.4 g/kg Cu and 0.7 g/kg Zn (German, 2001). Marsalek and Marsalek (1997) showed that 70–90% of total metals in pond sediment was in potentially mobile forms.

Stormwater infiltration has been a widespread best management practice since the early days of stormwater management. At first, stormwater infiltration was regarded as a cost-effective way to reduce runoff volumes and as an alternative to pipe systems, mostly in residential areas. As the awareness of stormwater pollution increased, the pollution retention capabilities of the infiltration facilities have gained more interest as well as the risk for soil and groundwater contamination. The design of infiltration facilities is truly site specific (e.g. dependent on soil characteristics) and pollutant trapping may vary a lot between dif-
different facilities. The general perception is that the stormwater pollutants end up in the upper soil layers (Wigington et al., 1986; Mikkelsen et al., 1996; Dierkes and Geiger, 1999). However, studies of heavy metal mobility in soil-monoliths (lysimeter test, soil depth 35 cm) have shown that approximately 50% of Cu and 10% of Zn may end up in the effluent water (Dierkes and Geiger, 1999) (Table 2). Norrström and Jacks (1998) showed that Pb, Cu and Zn in roadside soils are vulnerable to leaching when exposed to a high NaCl concentration, reducing conditions or to a lowering in pH.

In a catchbasin perspective it is not really appropriate to talk about pollutant removal since the only thing that normally happens is that pollutants are redistributed within the catchbasin. True pollutant removal can only be achieved if the pollutant sources are eliminated. Until that is reached, we should have the best possible control of the pollutant fluxes in the watershed. It is clear that a well-designed pond or an infiltration system retains a majority of the heavy metals carried by urban runoff (Table 2). However, we still need to discuss, and sometimes even doubt, if the pollutant trapping efficiencies are satisfactory and if the pollutants are safely stored in the stormwater sediments or soil.

The concentration of many heavy metals in sediment and in outgoing water of a pond during storm events may be characterised as high, according to guidelines from the Swedish EPA (German, 2001). This statement is also valid for the effluent water from stormwater infiltration. Consequently, stormwater treatment in ponds or infiltration units does not eliminate the risks of acute effects on the ecosystem in the receiving water. Notably, heavy metal concentrations in treated stormwater are in almost all cases lower than the permissible concentrations stipulated in the guidelines for drinking water.

Based on the studies cited here, we can assume that approximately 50% of the load of copper may directly escape the stormwater pond or the stormwater infiltration facility. Furthermore, the possible mobilisation of pollutants bound to sediment and soil may further increase the pollutant transport to surface water or ground water. Thus, the traditional BMPs (i.e. ponds and infiltration units) may not be good enough if we want to sustain a good water quality in the receiving waters. Possible ways to improve stormwater pollution control have been investigated during recent years, for example constructed filters with zeolit, peat or iron oxide coated sand (Sansalone, 1999; Färm, 2001) and source control measures such as street sweeping (German, 2001).

**Screening**

When a strategy for the abatement of pollution from stormwater is to be developed, there are several aspects to be considered – political, public opinion, economics, local conditions, technical possibilities and so on. In this paper we are focusing on two aspects, or “screens” as in Figure 1: 1) Standards and legislation and 2) Sustainability.

**Screen 1 – standards and legislation**

Discharges from wastewater treatment plants are strongly regulated in Sweden, but apart from bathing water quality criteria, there are very few regulations related to stormwater discharges. The local environmental administration can, however, lay down their own

<table>
<thead>
<tr>
<th>To sediment or soil</th>
<th>To surface water</th>
<th>To ground water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cu</strong></td>
<td><strong>Zn</strong></td>
<td><strong>Cu</strong></td>
</tr>
<tr>
<td>Wet pond¹</td>
<td>30–75%</td>
<td>30–82%</td>
</tr>
<tr>
<td>Infiltration²</td>
<td>43–61%</td>
<td>84–94%</td>
</tr>
</tbody>
</table>

¹ From Pettersson et al., 1999
² From Dierkes and Geiger, 1999
regulations based on various principles. In most cases, these focus on aesthetic effects, physical impacts such as peak flows causing erosion of river beds, but DO depletion and pollution with individual compounds such as heavy metals or oils are also sometimes used.

The Water Framework Directive, adopted by the European Union in December 2000, will also encompass stormwater discharges when it is enforced. The directive is a complex and ambiguous legal text that does not mention stormwater in any detail and has not yet been implemented nationally. The system boundary in the Water Framework Directive is the river basin, or the catchment area. The directive includes both surface waters and ground water. The goal for the directive is to achieve “good surface water status” and “good groundwater status”. The surface water status is composed of “good ecological status” and “good chemical status”. In short, this implies that the water quality of the receiving water, whether surface water or groundwater, should not deviate from the given standards for hazardous substances and that the conditions in the water should in principal not deviate from natural conditions. Further, the use of water will be regulated so that the natural capacity is not overexploited. The effects of the directive on the management of stormwater are unclear.

Discharges of stormwater from roads and urban areas certainly affect the receiving water quality and must be included in the integrated planning of the catchment area. The extent to which stormwater is a major source of polluting substances to the receiving water varies considerably, from next to nothing in distant areas to a considerable extent close to major highways or city centres. Several substances on the EU proposed list of hazardous substances are to be found in stormwater, e.g. cadmium, PAHs, and lead. Although the priority hazardous substances will be phased out, there are several other more or less hazardous substances for which stormwater is a major source, e.g. several heavy metals like copper, zinc and platinum. The discharge of polluted stormwater should be viewed in the context of all the discharges in a catchment area, and the quality of the water. In some cases stormwater can probably be discharged without treatment, while in other cases, e.g. in a sensitive water area, the stormwater should be treated in some way.

A presentation of applied Best Management Practices (BMPs) in Sweden and Denmark has been made by Mikkelsen et al. (2001). In this paper, the sustainability of the BMPs in relation to e.g. the EU Water Framework Directive is also discussed. Special concern should be given to the increasing use of stormwater infiltration as a BMP. Especially in the light of the goals of the directive, where groundwater is an equally important issue as surface waters, stormwater infiltration should be questioned in each case. The question whether the stormwater pollutants should be disposed off to the surface water or to the groundwater should be put. For many catchment areas the only reasonable answer will be that neither of the two alternatives is sustainable, but that the pollutant sources should be taken care of. The directive states that in urbanised areas less severe goals may be set for

**Figure 1** Visualisation of screening analysis of stormwater strategies

![Diagram of screening analysis of stormwater strategies]

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the quality of surface waters and ground water. This implies for example that stormwater infiltration may be considered if the groundwater already has a low quality. However, one goal of the directive is that the quality of surface- and groundwater should not be further deteriorated.

**Screen 2 – sustainability criteria**

Several approaches to define the word “sustainable” exist, among them the Brundtland commission, the Rio declaration and the European Water 21 project. In short, the Brundtland report focuses on the needs of future generations, the Rio declaration on the fairness of the use of natural resources, and the Water 21 approach on the use of natural capital. The Swedish way is to integrate and encapsulate these and other approaches into 15 environmental objectives. These objectives have been adopted by the Swedish parliament. The environmental objectives articulate, in a normative way, future states that are desirable. Focus is put on questions about human health, biological diversity, cultural environment and nature. Six of the fifteen objectives seem relevant for stormwater: natural acidification only, no eutrophication, a non-toxic environment, high-quality groundwater, flourishing wetlands, and a good urban environment.

**Natural acidification only.** Stormwater from rural areas may have a low or very low pH, especially in springtime when the snow melts ("acid-shock").

**No eutrophication.** Stormwater may carry considerable amounts of phosphorus and nitrogen to the receiving waters, but usually other sources of nutrients are dominant.

**A non-toxic environment.** The contribution from stormwater of heavy metals, PAHs, pesticides and other potentially hazardous substances may be dominant compared to other sources. This may be especially pronounced in springtime, when the fauna in the receiving waters is extra sensitive.

**High-quality groundwater.** Stormwater may be brought to the groundwater naturally, or intentionally by infiltration, open ditches etc. Since the soluble part of especially the heavy metals is considerable (normally between 20 and 70%), there is a risk of groundwater pollution. On the other hand, stormwater infiltration may help to preserve the natural groundwater balance in an urban area.

**Flourishing wetlands.** The construction of artificial wetlands for the treatment of stormwater is increasing in Sweden. It may be discussed if these wetlands are part of nature or treatment facilities. Either way, the experiences are that they promote a good bio-diversity in the area.

**A good urban environment.** This is a complex objective that may include hygienic aspects and aesthetical aspects. Stormwater may be hygienically hazardous due to the soiling from animals and birds. On the other hand, open stormwater facilities like ponds and wetlands may enhance the aesthetical values in a city.

**Conclusions**

Stormwater is most likely an important pathway for pollutants in a catchbasin perspective. The significance of stormwater depends on catchment composition (e.g. degree of urbanisation) and type of pollutant (e.g. heavy metals). However, we have found that it can be complicated to evaluate the relative importance of stormwater as a pollutant source in a
catchbasin since the calculations often are based on standard concentrations rather than measured values. The use of standard concentrations does not incorporate the variations in stormwater quality, both with respect to time and space. We need to have more efficient methods to measure the fluxes of stormwater pollutants. A control programme needs to be developed which includes an identification of hotspots, regular sediment sampling and measurements of river water quality. Existing stormwater facilities should be put under an observation programme to evaluate outgoing water quality in order to find out if the BMPs actually protect the environment. It is important to note that today’s BMPs are not removing the pollutants in a catchbasin perspective, since the only thing that normally happens is that pollutants are redistributed within the catchbasin. True pollutant removal can only be achieved if the pollutant sources are eliminated. Until that is reached, we should have the best possible control of the pollutant fluxes in the watershed. As this study has shown, we can doubt if the conventional BMPs, such as stormwater ponds and infiltration facilities, produce a sufficient pollutant control. Dissolved substances may escape treatment and pollutants trapped in sediment or soil may become mobile.

Many aspects need to be considered when future strategies for stormwater management are selected. However, no clear definition of sustainable urban drainage exists today and the goals for stormwater defined in the legislation (e.g. The EU Water Framework Directive) are not clear. This study indicates that the complex selection process could be more accurate if different “screens” are used. The screens discussed in this paper may serve as a starting point for further development of a well-defined screening analysis. The Swedish environmental objectives, which try to encapsulate the major aspects of environmental sustainability, may be used as a foundation for a “sustainability screen”. By using this screen, the “unsustainable” features of different stormwater strategies could be pointed out. A “standards and legislation screen” will be based on the EU Water Framework Directive, even though this legal text has not yet been fully adapted on the national level. One goal of the directive is that the quality of surface- and groundwater should not be further deteriorated. Consequently, many of the conventional BMPs (e.g. stormwater ponds and infiltration units) may not be applicable in areas where the receiving water has a good water status, since the level of pollution control is too low or unreliable. In future studies we intend to apply the suggested screens on the catchbasin level.

Finally, the catchbasin perspective does not replace the perspective of the local stream where stormwater is discharged. The local effects (e.g. acute effects on biota) are equally important also in the future.

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