Toward Sustainable Urban Stormwater Management

As a result of the decision made in the nineties to install separate stormwater drainage for settlements, our current methods of wastewater disposal will change considerably in future years and decades. There is, however, more and more evidence that also rain water carries a certain pollutant load. In order to find suitable measures for the protection of the environment, sources, concentrations and hydraulic dynamics need to be well characterized. This article introduces instruments for the reduction of substantial load and first steps of their implementation.

Most of the rain water in Switzerland is still collected in combined sewer systems. Rain water is therefore mixed with waste water from households and industries before it is treated in a sewage treatment plant and eventually discharged into receiving waters. The early nineties brought about a process of rethinking. The detour via treatment plants was considered not to be appropriate for the less unpolluted rain water, which should rather be infiltrated on site or be discharged separately from waste water. In the meantime, however, it has become clear that rain water carries pollutants and that the earlier assessment was too optimistic, especially in case of runoff from impervious surfaces such as roofs and roads. Appropriate measures for the prevention of water pollution and the protection of soils and sediments must be based on knowledge of the substances carried by rain water and their behavior in the environment. Therefore, EAWAG is involved in various projects dealing with sustainable urban stormwater management. This article gives an overview of current research projects and introduces possible measures.

The Properties of Surfaces Count

Surface runoff originates from a diversity of surfaces consisting of many different materials which is why any effort to assess the properties of surface runoff for every single possible case is impractical. Nevertheless, in order to cover a maximum number of situations, urban surfaces are classified according to their specific pollution potential (Tab. 1), a vital step in order to provide a practical instrument for the user. Accordingly, public authorities and professional associations have worked out a number of guidelines during the last few years, such as the recommendations on “Water protection in drainage of traffic routes” and the guideline on “Stormwater management” [1, 2]. Traffic routes (roads, aerodromes and rail) cover roughly 60% and roofs approxi-

Surface	Indication of pollution potential in surface runoff	Classification of pollution
Roofs and green areas		
Green areas and green roofs without pesticide containing linings	Good and efficient retention of water and contaminants on the roof.	low
Roofs of mainly inert materials and low metal content, glass roofs, terraces	Contamination similar to rain water. Slow accumulation of pollutants in infiltration sites.	low
Roofs of mainly inert materials and usual degree of metal containing installations such as Cu, Sn, Zn and Pb	Rapid accumulation of heavy metals in infiltration sites. Heavy metal adsorbents are recommended for roofs with metal areas of 20–50 m^2.	medium
Roofs with higher content of metal sheets from Cu, Sn, Zn, Pb	The protection of soil and water requires treatment of the surface runoff from these roofs. The following areas are considered as heavily polluted: a) in case of infiltration >50 m^2 b) in case of direct discharge >500 m^2.	high
Parking lots, driveways and roads		
Driveways, private and public parking in residential areas, bicycle tracks, pavements, small roads without high traffic densitiy	Low pollution potential under normal use. Partial biodegradation of organics where areas are permeable.	low
Shipment and storage space and working areas with handling of hazardous substances	Loss of fuel, contaminants from maintenance work, shipment and storage may lead to soil and groundwater pollution.	medium
Public parking with high traffic density (e.g. shopping centers)	Increased soil and groundwater pollution potential. If made permeable, some organics may be biodegraded in top soil.	medium to high
Roads	Pollution potential depending on traffic volume, types of vehicles, way of driving and maintenance. Perpendicular to the road, contaminations with heavy metals and PAH (polycyclic aromatic hydrocarbons) mostly decrease with increasing distance from the road.	depending on traffic volume

Tab. 1: Classification of urban surfaces according to their pollution potential.

Para-meter	Unit	Green roof	Gravel roof	Tile roof with metal installations	Metal roof from Cu, Zn, Pb	Motorway	Urban roads
Reference		EAWAG	EAWAG	EAWAG	EAWAG	EAWAG	Xanthopoulos & Hahn [10]
pH		6.7–7.5	5.5–7.9	5.5–7.5	–	7.0–7.5	6.4
TOC	mg C/l	4–20	5–10	5–15	–	10–20	–
DOC	mg C/l	–	3–10	2–14	–	5–10	12
TSS	mg/l	–	2–5	15–40	–	150–250	560
NO_3	mg N/l	1–2	2–5	0.3–0.7	–	6	0.6
Ca	mg/l	20–60	10–25	1.5–2.5	–	–	–
Pb	µg/l	6–15	2–10	10–70	5000–7000	300	311
Cd	µg/l	u.E.g.	0.05–0.1	0.1–0.5	–	4.5	6.4
Cu	µg/l	5–10	15–25	100–300	800–2000	150	108
Zn	µg/l	u.E.g.	10–40	50–200	1000–4000	500	603
PAH	µg/l	–	–	–	–	3	3.1
Atrazine	ng/l	–	100	100–1600	–	–	–
Mecoprop	ng/l	–	1500–5000	–	–	–	–

Tab. 3: Weight mean concentrations in different runoffs from roofs and roads.
TOC = total organic carbon, DOC = dissolved organic carbon, TSS = total suspended solids, PAH = polycyclic aromatic hydrocarbons.

mately 30% of the impervious surfaces in Switzerland. Therefore, the main focus has to be on pollutants emitted from these surfaces (Tab. 2). Table 3 shows the average concentration of pollutants for different roofs and roads.

Heavy metals washed off roofs are predominant in the total runoff from settlements. Depending on the catchment, copper emitted from roofs, e.g., can form a fraction of 30–60% of the total copper load in urban waste water. A study on metals currently used in roof construction showed that 30% of all metal materials are zinc and 70% copper. The equivalent is a per capita amount of 2.9 m^2 of copper sheet.

Source	Contaminant
Roofs	
Metal installations, sheets, facades	Cu, Zn, Pb, Sn
Atmospheric washout	Pesticides (e.g. Atrazine)
Flat roof linings	Pesticides (e.g. Mecoprop)
Roads	
Gasoline, Catalyst	Pb, Ni, Co, Pt, Pd, Rh, PAH, MTBE
Brakes	Cu, Cr, Ni, Pb, Zn, Fe
Tires	Zn, Pb, Cu, Cr, Ni, Cd
Road material	Ni, Mn, Pb,Cr, Zn, As, PAH
Road maintenance	Pesticides, salts

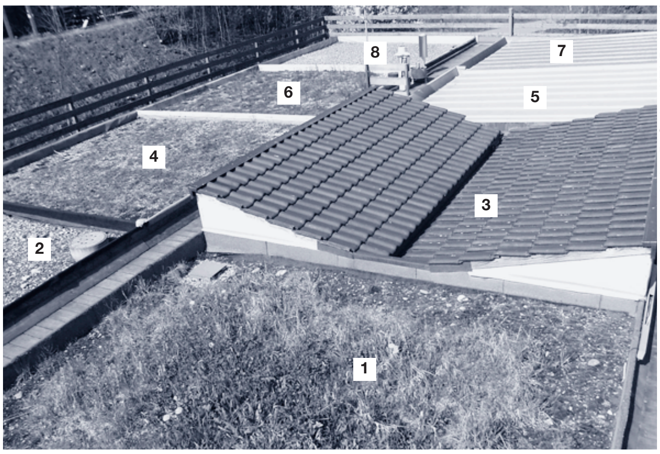
Tab. 2: Contaminants in stormwater runoff from roofs and roads.

Pollutants from Roofs and Roads

At present, EAWAG, working together with the Laboratory for Water Protection of the Canton Berne and the Technical College in Burgdorf, examines the behavior of different model roofs during rain weather. A gravel flat roof as reference roof, four green flat roofs, a tiled roof with copper installations and two metal roofs made of copper titanium zinc and tinned copper sheet are being probed simultaneously (Fig. 1). Furthermore, the runoff from the metal roofs is collected and deviated over an adsorbing filter in order to test its retention capacity. Not surprisingly, the roofs with metal components show higher rates of copper and zinc drainage (Fig. 2). However, more than 97% of the metals are retained by the adsorbent.

In two other projects, the project team in Burgdorf analyses the runoff and the further fate of contaminants from a highly frequented road (Fig. 3). On one hand, runoff from the road is led over three differently composed adsorbents. First results show that the most efficient of the three filters retains more than 95% of copper and zinc from the road runoff. On the other hand, a road shoulder which has been subject to traffic for 30 years is investigated in order to gain information on transport and accumulation of specific traffic induced contaminants in the soil, as well as ideas on the construction of future road shoulders.

The concentration of pollutants varies considerably depending on the surface and the



Photographs: B. Gerber, HTA Burgdorf

Fig. 1: Model roofs examined by EAWAG.

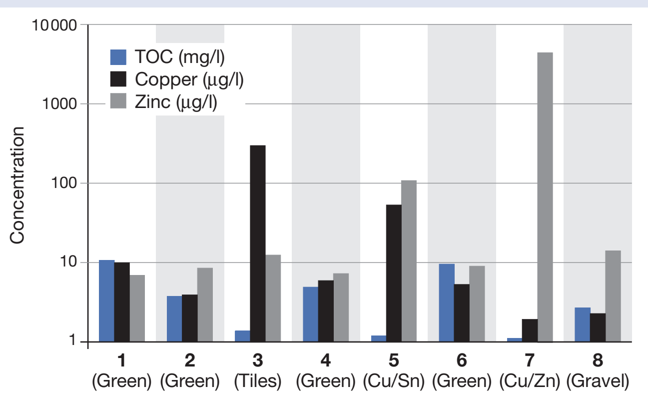


Fig. 2: Average copper, zinc and TOC-concentrations in the runoff of the examined model roofs. TOC = total organic carbon.

Fig. 3: Connection of the road runoff with the test facility.

duration of a rain event. Especially at the beginning of a rain event, during the so-called "first flush", great amounts of pollutants are carried away (Fig. 4) [3]. However, there are also substances which only become mobile after a longer duration of rainfall, such as the pesticide Mecoprop, used in insulation sheets of flat roofs. It only dissolves after the roof has been sufficiently moistened (Fig. 3).

Effects of the New Stormwater Management

The new pathways for stormwater runoff are clearly defined in Swiss legislation and guidelines. The priorities are: 1. decentralized infiltration, 2. direct discharge into surface waters, and 3. discharge into combined sewers. Furthermore, there is an increasing interest in the further use of storm water [4].

Yet, whatever pathway the storm water takes or how it may be used, the pollutants contained cause increasing pollution of soils, sediments and surface waters. One example are the copper concentrations in sediments of Lake Geneva near Lausanne, which clearly document how discharge from combined or separate sewer systems pollute the environment (Fig. 5) [5]. At the discharge site, concentrations of more than 500 mg copper per kg sediment can be measured. A parallel study at the same site revealed that the plankton is also highly affected by the wastewater discharge [5].
As the new directives for urban stormwater drainage are mainly applied for renovated or new buildings, the new stormwater management will only be implemented step by step during the next decades. Hence, there is sufficient time for the necessary development of innovative measures which guarantee pollution of the environment by stormwater discharge be reduced to a minimum. In general, there are two ways of controlling the runoff quality: source control and the development of barrier systems.

Source Control

The key to advances in sustainability is the control of pollutant emissions at the source. This is possible by means of legislation, economical incentives and voluntary renunciation which will normally lead to a practicable long term solution. However, as pollutants accumulate in soils and sediments very slowly, environmental effects will only become visible after decades. Therefore, there is only restricted political awareness and as a result restrictions on a legal basis are barely feasible. Yet, information and education of stakeholders with respect to environmental and ecotoxicological issues, guidelines for the use of building materials for houses, roads and motor vehicles, as well as the perception of the public for certain environmental problems should be promoted. A very positive example in this context is the recommendation for architects and clients given by the Swiss federal coordinating authority for building and real estate on "metals for roofs and facades" which facilitates the choice of environmen-

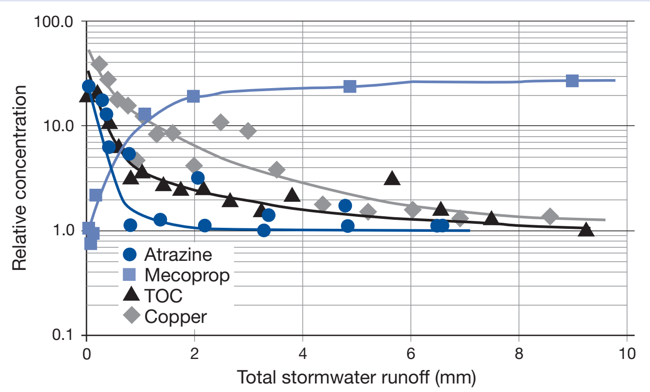


Fig. 4: First flush patterns of different pollutants in roof runoff. Atrazine and Mecoprop are pesticides. TOC = total organic carbon.

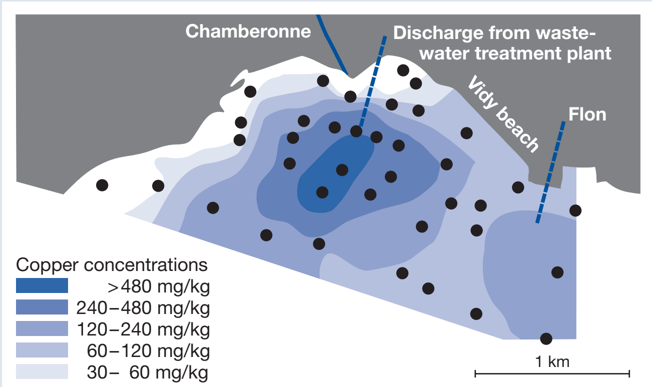


Fig. 5: Accumulation of copper in the sediments of the bay of Lausanne as a result of wastewater discharge.

tally harmless metals for the cladding of buildings. Copper, zinc and lead are identified as most hazardous substances and alternatives are shown [6].

Setting up Barriers

Despite increasing efforts into source control, one must be aware that large amounts of undesirable materials are currently installed in buildings and that it will take decades to replace them by more environmentally friendly materials. Until this goal has been reached, the emission of heavy metals caused by corrosion and of organic micropollutants will steadily increase. In order to avoid further spreading, specially designed barrier systems are needed, which ensure the best possible protection of waters, soils and sediments. Setting up barriers to the transport of certain substances is a technical option to divert, separate or concentrate pollutants. However, barrier systems do not achieve a 100% elimination of substances. At present, infiltration into natural soils and passage through granulated adsorbents are suggested barrier systems.

Natural soil passage: Natural soils with sufficient permeability are suitable for the retention of pollutants. The soil material is usually available on site and can be used in infiltration basins. Various investigations have shown that retention of pollutants occurs mainly in the top 30–50 cm of the soil. Being not degradable, they accumulate over a long period of time and the permitted pollutant limits given by legislation will sooner or later be exceeded. The drawback of soil passage is that a natural good is used for the retention of contaminants and therefore turns into hazardous waste. Remediation or deposition of such soils is necessary at the latest when infiltration basins are deconstructed.

Artificial adsorber systems: Because special adsorber layers have significantly higher retention capacities, the volume of polluted soils can be reduced and the efficiency is higher than that of natural soils. Various laboratory and pilot studies at EAWAG and first major installations have shown that the adsorber systems serve their purpose [7]. Among different media proposed as adsorbing layers, granulated iron-hydroxide has proven to be especially suitable for the removal of heavy metals (Fig. 6). Compared to natural soils, the adsorption capacity achieved with this material is ten times higher, thus eventually reducing deposition volumes.

Because of this excellent performance, the guidelines of the Swiss Water Pollution Control Association demand adsorber systems of different types for the infiltration of runoff from roofs with copper and zinc surfaces of over 50 m^2 and for direct discharge from roofs of more than 500 m^2 [2].

Blue-green Environments

Traditionally, efforts have been made to hide the stormwater drainage underground. Today, architects and engineers are called upon to integrate the rain water into so-called blue-green environments and thus make it visible. The new technical systems for stormwater management may be designed in a way that the desired tasks as retention, contaminant barrier, infiltration and direct discharge can be combined in a creative manner and also fulfill aesthetic requirements when integrated in settlements. Green roofs, open channels, small creeks, ponds, reed beds and other planted units may become elements of landscaping which accompany the rainwater until infiltration, direct discharge or reuse [8, 9].

Challenge for Engineers, Scientists and Inventors

The implementation of the new ideas on stormwater handling will take decades. Renovation of the stormwater drainage systems may be considered as part of a more integral development of urban water concepts where changes in water supply and wastewater management should take place simultaneously. An important element is the separation of water fluxes from settlements according to their quality. Dual systems for water supply (separation of drinking water and service water), the separation of wastewater fluxes into grey and black water, urine separation, nutrient management at the source as well as dry toilets and other alternatives of sanitation facilities are currently studied in science and practice. The new urban water concepts challenge engineers, scientists and inventors to study and introduce innovative technologies and solutions, thus increasing sustainability in future urban water management.

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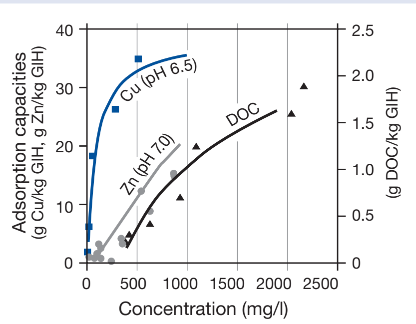

Fig. 6: Adsorption isothermes for copper, zinc and DOC on granulated iron-hydroxide. DOC = dissolved organic carbon.

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