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TRACKING HEAVY METALS REVEALS SUSTAINABILITY DEFICITS OF URBAN DRAINAGE SYSTEMS

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ABSTRACT

Heavy metals such as cadmium, copper, lead and zinc are the critical metals in domestic wastewaters. Based on mass flow studies, the runoff from roofs and streets contribute 50-80% of these metals to the total mass flow in domestic sewage. Depending on the sewerage concept, the metals accumulate in different environmental compartments. With the combined sewer system, most commonly applied, the major part of the metals is bound to the sludge during sewage treatment. If the sludge is used in agriculture, the metals are enriched slowly in the top soils. With separate sewer systems, the metal loads to the receiving waters are increased, finally leading to accumulation in the sediments. If the new concept for the infiltration of runoff waters is applied, rapid and concentrated accumulation at the infiltration sites will occur. As a short term measure, new adsorptive elements in infiltration facilities would allow us to control the accumulation. The deposition of heavy metals in the environment cannot be avoided as long as no further efforts are made to reduce metal emission at the source. New partnerships between environmental/sanitary engineers and other professional groups such as architects, plumbers, car engineers, material technologists have to be established in order to minimize diffuse longterm deposition of hazardous substances and to be able to realize sustainable small water cycles without negative side-effects. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Accumulation; heavy metals; receiving water; road; roof; runoff; sewer system; sludge; storm water; sustainability; urban drainage system; wastewater.

INTRODUCTION

In the past decades, urban drainage systems of mainly European and American cities were designed to transport all types of polluted and non-polluted excess waters as complete and as fast as possible out of urban areas into the receiving waters. The aim of such concepts was to maintain hygienic conditions and to avoid damage caused by flooding of residential and industrial areas. The idea of a fast export of used and naturally occurring waters from urbanized areas lead to numerous technical water transport facilities. Massive efforts were made to put small water courses into separate or combined sewer systems, to connect drainage systems for groundwater abstraction and public fountain discharges to public sewers and to guide runoff water from roofs, roads and other impervious areas into the nearest sewer. Apart from ever growing networks for public drinking water supplies which transport water to satisfy maximum needs from sometimes fairly distant water resources, widespread and costly canal systems were constructed to transport excess water back to the drinking water resources. In order to keep up such manmade water cycles, drinking water treatment and wastewater treatment serve to control desired water quality levels in receiving waters, in drinking water and wastewater discharges. Over the last three decades, the control measures to satisfy the quality goals in receiving waters increased tremendously and lead to a fast succession of new and additional treatment technologies. The original ideas of the sixties to guarantee water pollution control by BOD-removal facilities were soon outdated and additional requirements such as P-removal, nitrification, N-removal, sludge handling, removal of non-biodegradables, and heavy metal removal asked for rapid upgrading and increasing investments in wastewater treatment. Figure 1 shows the development of the wastewater treatment technology realized in the course of time in Switzerland. Time history demonstrates that as soon as one problem is tackled new demands arise for further treatment. From a perspective of the sixties BOD- and P-removal were the ultimate goals. However, since about 1980 wastewater engineers and plant operators are increasingly faced with a series of new problems. These will most probably be followed by other yet undefined requirements asking for increasing investments and operating costs in the near future. In Switzerland, the investment costs for the existing technical transport and treatment systems amounted to $ 1700.- per inhabitant over a period of about 30 years. In order to accelerate completion of the drainage and treatment facilities, constructions were subsidized to a great extent by the government. Nowadays, as many of the installations reach their lifetime, renewal, reconstruction and replacement lead to new investments in the same order of magnitude. Since the communities are obliged to finance new projects from their own funds, local authorities start to get more involved in our technical water cycles. This is now the chance to discuss and introduce ideas on new concepts which differ from traditional solutions and in which more attention is paid to mass flows and their management of environmentally harmful matter and to energy flows needed to operate the water transport and treatment facilities.

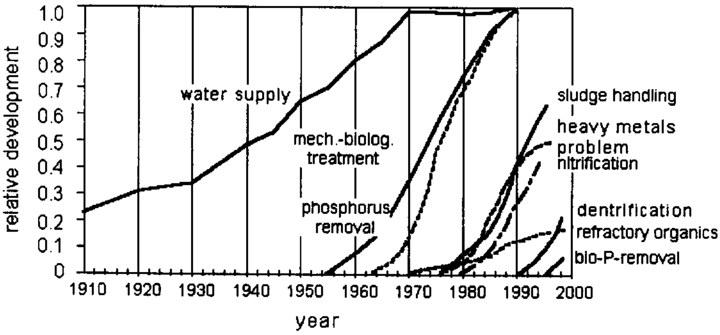

Fig. 1. Development of wastewater treatment technologies in Switzerland.

Analyzing the present situation of urban water supply and drainage systems, it becomes obvious that enormous amounts of water are transported over large distances and originally unpolluted water is mixed with wastewater leading to undesired dilution. Redirection of parts of the urban water flow is essential to create decentralized small water cycles in which (1) local drinking water resources are rediscovered, (2) used water may be recycled, (3) compost toilets may be introduced, (4) nutrients are recycled, and (5) storm water may be used or infiltrated into the underground. From a sustainability point of view, many of these measures may sound attractive, however, in most cases our society is presently not ready to change its behavior, which is necessary to accept such drastic changes. Among alternative ways of redirecting water flows, storm water infiltration is considered to be most accepted and, in many countries, water management legislation is revised in order to promote this solution. In Switzerland, if technically feasible, storm water from impervious areas such as roofs and roads has had to be infiltrated or otherwise discharged directly into receiving waters since 1991.

STORM WATER INFILTRATION – A SUSTAINABLE ELEMENT OF URBAN DRAINAGE SYSTEMS?

Water authorities are currently working out detailed guidelines on design and construction of different types of infiltration facilities. Decentralized infiltration shafts, pits, ponds, subterranean galleries, and many ways of creating pervious areas are proposed (GSA Bern, 1994, AGW Zürich, 1996). The advantages of storm water infiltration such as

- decrease of hydraulic loads to wastewater treatment plants
- decrease of sewage overflows from combined sewers
- decrease of peak flows in urban drainage systems
- increase of groundwater infiltration
- soil passage of polluted storm water protects groundwater

are put forward and convince engineers and public authorities to disconnect all clean water sources from sewer systems. The guidelines are based on the idea that storm water would be undoubtedly unpolluted or weakly concentrated allowing direct discharge into the underground. It is commonly agreed that with road runoff this assumption does not hold true and additional measures have to be taken to pre-treat this water by building up local treatment systems such as humus passage ponds, gravel filters or physical-chemical treatment plants before the water is recycled into the natural environment. Runoff from roofs and other less polluted impervious areas are certainly less concentrated but contain similar types of substances originating from diffuse pollution sources. Many of these substances are strongly adsorbing on solid surfaces such as heavy metals, polyaromatic hydrocarbons, adsorbable organic halogens and other compounds. In these cases, environmental concern is focused mainly on pollutant loads and less on pollutant concentrations that occur in nature. From this point of view, the main difference between a highly and a weakly concentrated runoff water is the rate of substance accumulation at a certain site where the runoff water is disposed of. If storm water infiltration concepts are applied, it is the infiltration facility which is increasingly loaded with pollutants leading to a patchwork of small but numerous deposit sites. Eventually, these sites may leak in a later stage of accumulation and threaten the groundwater quality. Besides the many positive aspects of storm water infiltration, some questions concerning the fate of certain pollutants remain yet unanswered. The following properties of storm water infiltration practice may give rise to preference for traditional drainage solutions

- deterioration of soil quality at infiltration sites by adsorption of heavy metals and non-biodegradable organic substances
- increase of the pollutant loading rates by a factor of 5 to 100 by concentrating large runoff areas in small infiltration sites
- decrease of groundwater quality by infiltration of hydrophilic substances and potential leakage of accumulated pollutants
- increased transport of colloidal and dissolved matter to the groundwater by exclusion of humus surface layers at infiltration sites
- increased potential risk for soil and groundwater by mismanipulation and accidents with chemicals in the catchment of infiltration sites.

In order to get more insight into qualitative problems connected to storm water infiltration, several studies concerning the quality of road and roof runoff, mass flow and fate of pollutants in different urban drainage alternatives and the significance of storm water infiltration in a regional water budget were conducted at EWAG. As will be shown later, some pollutants contained in runoff waters, above all heavy metals, represent nowadays the major part of the total mass flow from urban drainage systems. Therefore, redirection of storm water flows from the traditional combined sewer system to separate systems with direct discharge into receiving waters or infiltration into the underground leads to pollutant accumulation in different environmental compartments. In Figure 2, the three pathways substances may go in alternative drainage systems is shown. Concentrating on heavy metals, the dominant mass in combined sewer systems flows to the treatment plant where it is transferred from an aqueous or suspended phase into the sludge.

Depending on the final deposition of the sludge, heavy metals accumulate in deposit sites as dried sludge or as slag or on agricultural land when the sludge is used as fertilizer. In separate sewer systems, a substantial part of the total mass flow of heavy metals is discharged into receiving waters where the accumulation takes place in the solid phase of the sediments. Finally, decentralized infiltration of runoff waters into the underground causes a rapid accumulation in the vadose zone of infiltration plants.

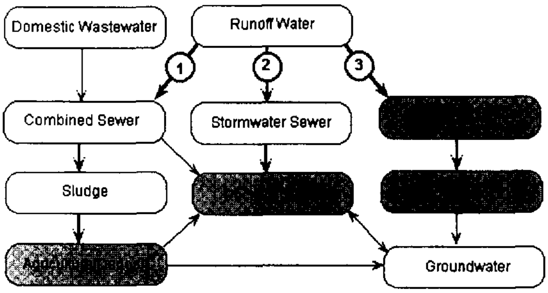

Fig. 2. Pollutant pathways in alternative urban drainage systems
1: Combined sewer system, 2: Separate sewer system, 3: Separate runoff infiltration.

STORM WATER TRANSPORTS HEAVY METALS

Mass flow analysis of pollutants in storm water is particularly complex because the parameters which determine concentrations and loads in runoff waters are numerous and often unknown. Duration of preceding dry periods, rain intensity and duration, atmospheric pollution, dry deposition, and materials in contact with the runoff water are some variables leading to a large variation of analytical results from different storm events. In addition, the extremely dynamic nature of pollutant washoff makes the estimation of average event concentrations and loads more difficult. Among the various substances found in storm water, heavy metals are especially suited to track the pathways of storm water pollutants. They are always present and often highly concentrated, not biodegradable and show a distinct accumulation behavior on solid surfaces. Therefore, metal loads and accumulation rates can be determined and located in the environment. Among the various metals contained in storm water, Cadmium (Cd), Copper (Cu), Lead (Pb), Zinc (Zn), and eventually Nickel (Ni) are potentially most hazardous. Detailed literature surveys (Mottier and Boller, 1992, Schläpfer *et al.*, 1996) and measurements in roof runoffs in the city of Zurich (Mottier *et al.*, 1995) are available to evaluate the significance of storm water pollution. In Table 1, a summary of average concentrations found in rain, road and roof runoff are shown.

Table 1. Average pollutant concentrations found in storm water and storm water runoff

Parameter		**Storm water concentration**	**Road runoff concentration**	**Roof runoff concentration (Literature)**	**Roof runoff concentration (Measurements*)**
pH		4.0 - 6.9			5.2 - 7.7
TSS	mg/l	8.5	240	65	21
TOC	mg/l	2	16		9.1
DOC	mg/l	1.2	7		4.3
Pb	µg/l	3	300	90	16
Cd	µg/l	0.1	4	0.6	0.17
Cu	µg/l	3	150	200	225
Zn	µg/l	15	500	400	42

* Average from a tile and a polyester roof (Mottier and Boller,1996)

From these concentrations, average load values per runoff area can be calculated and extrapolated to annual mass rates which are necessary to establish mass flow schemes for alternative drainage concepts. However, these values do not reflect the highly dynamic nature of runoff pollution. Many of the substances, including heavy metals, show a distinct first flush phenomenon. The concentrations are extremely high in the first minutes of a storm event and decrease later exponentially towards rain concentrations. Usually, these dynamic effects are observed during the first 2 mm runoff height. As an example, first flush heavy metal concentrations from three types of roofs are shown in Table 2 and can be compared to the average runoff concentrations in Table 1.

Table 2. First flush concentrations in the runoff water of different roofs

		Tile roof	Polyester roof	Flat gravel roof
Cu	μg/l	1905	6817	140
Zn	μg/l	360	2076	36
Cd	μg/l	2.1	3.1	0.2
Pb	μg/l	172	510	22

These and other investigations of runoff from roofs of different materials revealed considerable differences with respect to Cu and Zn concentrations. Especially copper installations on buildings seem to represent the largest source for the emission of this metal into the environment. For Zn, roof materials are next to traffic emissions one of the dominant sources. Based on studies by Barton (1973), zinc and copper corrosion from roof metal installations can be estimated to be 7-14 g Zn/m^2•a and 7.5 - 15 g Cu/m^2•a, respectively. Statistics on roof materials are scarce. For Austria, Stark *et al.* (1995) estimated the area of Zn and Cu sheets to be 3.3 - 6.4 m^2/inh. and 0.3 - 0.6 m^2/inh, respectively, leading to an inhabitant specific corrosion rate of 16-80 g Zn/inh•a and 2.5 - 9.0 g Cu/inh•a.

Case study: The city of Sankt Gallen

In order to follow the mass flow of the heavy metals originating from different sources within alternative urban drainage systems, a case study was conducted in the area of the city of Sankt Gallen in Switzerland. The observed area of 3900 ha with a population of 75000 inhabitants contains 1400 ha urbanized, 1400 ha agricultural and 975 ha forested land. Within the urban area a total roof area of 345 ha (46 m^2/inh.) and a total road area of 482 ha (64 m^2/inh.) are the main surfaces contributing to storm water runoff. The average annual rainfall amounts to 1292 mm from which about 80% may flow into the sewer system. In reality, only 51% of the rainfall on these surfaces or 5.5 million m^3/a reach the treatment plant. The domestic wastewater flow is estimated to be 17.2 million m^3/a. It is interesting to notice that from this amount 4.2 million m^3/a can be considered as unpolluted. In total only 57% of the water treated in the plant is purely domestic sewage. In Table 3, inhabitant specific water flows illustrate some important items of the water balance in the catchment area.

Table 3. Inhabitant specific water discharge from different activities and surfaces

	m^3/inh.		m^3/inh.
Raw wastewater	230	Storm water reaching sewer system	72
Household	77	from roofs	30
Industry	30	from roads	42
Unpolluted	56	Total storm water runoff	114
Storm water overflow	23	from roofs	47
Treated wastewater	207	from roads	66

Based on the heavy metal content of the sludge produced in the wastewater treatment plant of Sankt Gallen and on the metal loads carried by the storm water, the significance of different sources can be balanced. According to the annual metal loads, the relative contribution from storm water amounts to the values given in Figure 3. It has to be noted that the originally calculated loads do not account for Cu and Zn installations on roofs. A rough estimate based on the cited metal corrosion in Austria is also shown in Figure 3 and indicates that the storm water from roofs may represent more than 60% of the copper in combined sewers.

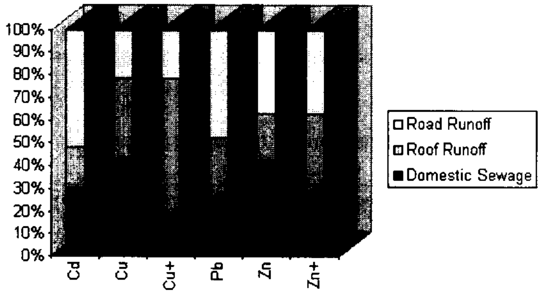

Fig. 3. Relative contribution of heavy metals from household, roof and road runoff in combined sewer systems. The columns Cu^+ and Zn^+ are values including average fractions of copper and zinc installations on roofs.

THE FATE OF HEAVY METALS IN ALTERNATIVE DRAINAGE SYSTEMS

The heavy metal loads from the different sources are transported through urban drainage systems and depending on the drainage concept they are brought through treated wastewater or sewage sludge into different locations of the natural environment. Since the major part of the considered metals are transported by storm water the pathway of this wastewater fraction in different drainage systems is essential. Three scenarios were considered to follow the mass flow of the four metals Cd, Cu, Pb and Zn including the alternatives of a purely combined, a purely separate sewer system and a system assuming 100% storm water infiltration.

Combined sewer system

Although the considered heavy metals are found dominantly as dissolved species in roof runoff, they usually react spontaneously with solid surfaces. Therefore, in combined sewers the major part is found in particulate form already in the raw wastewater. The highly reactive surface presented by colloidal matter in domestic sewage and by the biomass during biological treatment guarantee a relatively high removal rate in treatment plants and a high transfer into the sewage sludge. According to several investigations on the removal of heavy metals in mechanical-biological sewage treatment plants (Brunner, 1989, Candinas *et al.*, 1989, Schönberger, 1990), the average removal rates can be estimated to be 60%, 75%, 80% and 70% for Cd, Cu, Pb and Zn, respectively. For the combined sewer system, the mass flow from the sources to the different environmental compartments and finally to the final deposit site can be evaluated. Table 4 gives a summary of some important inhabitant specific metal loads occurring in this system.

As can be seen, the major part of the heavy metal mass flow ends up in the sewage sludge. Nowadays, the use of sludge in agriculture is decreasing. However, recycling of nutrients is supposed to be a goal of future sustainable urban drainage concepts. Therefore, a scenario of 70% sludge recycle was assumed to validate the effects of heavy metals mainly generated from diffuse sources and accumulated in sewage sludge. In the study area, about 164 m^2 of agricultural land per inhabitant is available for sludge disposal. Assuming an average sludge disposal rate of 1 ton dry matter/ha•3a and a mixing soil layer of 30 cm, the accumulation rates of heavy metals due to sludge use can be calculated. In addition, natural rainfall, dry deposition and the application of artificial fertilizers cause a further increase of the accumulation rates. It is interesting to notice that for the studied metals, except for copper, the accumulation rates due to the agricultural use of sludge are considerably smaller than for the other input items. From the accumulation rates the earliest time to reach the heavy metal standards for agricultural soils can be hypothetically estimated assuming no metal export by the plants and no decrease of heavy metal loads in future. With time periods of 250 years and more the results can be considered as not critical. Taking into account that especially soils in urban areas are already considerably pre-loaded with heavy metals, the time to reach the soil standards is still beyond 100 years. Although the accumulation of heavy metals in agricultural soils can considered to be a long-term problem, the strongly diffuse character of the pollution, the wide area affected and the slow and irreversible deterioration of the soil quality give rise to application of other than combined sewer systems.

Table 4. Heavy metal loads in g/inhabitant per year in the combined sewer system

Loads in g/inh·a	**Cd**	**Cu**	**Pb**	**Zn**
Input drainage system				
Domestic wastewater	0.015	4.0	2.5	20.0
Industrial wastewater	0.025	3.1	1.3	20.7
Unpolluted water	0.003	0.1	0.1	0.6
Road runoff	0.071	3.7	7.2	16.7
Roof runoff	0.020	6.1	3.9	12.5
Total	0.134	17.0	15.0	68.0
Loads to the receiving water				
Storm water overflow	0.013	1.5	1.3	7.2
Treatment plant effluent	0.049	3.6	2.6	20.4
Total	0.062	5.1	3.9	27.6
Loads into solids				
Sewage sludge	0.073	10.9	10.3	47.7
Grit chamber	0	1.0	0.8	3.2
Total	0.073	11.9	11.1	50.9

Separate sewer system

In separate sewer systems the storm water fraction is directly discharged into the receiving water. The water constituents in the storm water do not reach the wastewater treatment plant leading to a reduction of the metal content in the sludge. Since heavy metals strongly adsorb on solid surfaces, the major part will sooner or later be accumulated in the sediments of the receiving water. The specific loads which can be expected to reach the surface water from the study area are summarized in Table 5.

Table 5. Heavy metal loads in g/inhabitant per year in the separate sewer system

Loads in g/inh·a	**Cd**	**Cu**	**Pb**	**Zn**
Input drainage system sewage				
Domestic wastewater	0.015	4.0	2.5	20.0
Industrial wastewater	0.025	3.1	1.3	20.7
Unpolluted water	0.003	0.1	0.1	0.6
Input storm water drainage				
Road runoff	0.071	3.7	7.2	16.7
Roof runoff	0.020	6.1	3.9	12.5
Loads to the receiving water				
Separate storm water sewer	0.095	9.8	11.1	29.2
Treatment plant effluent	0.017	1.7	0.7	14.1
Total	0.112	11.5	11.8	43.3
Loads into solids				
Sewage sludge	0.026	5.0	2.7	33.0
Grit chamber	0	1.0	0.8	3.2
Total	0.026	6.0	3.5	36.2

Compared to the combined alternative the heavy metal loads in the sewage sludge are reduced but the loads to the receiving water are 2-3.5-fold larger in the separate sewer system. Again, the diffuse character of the metal deposition in the aquatic environment, the usually unknown affected section of a water course and uncertainties concerning the eco-toxicological effects of heavy metals in the sediments are some reasons to assess this alternative as unfavorable. In the case study, the receiving water is a comparatively small river where the loads are diluted by only a factor of one. At this low dilution rate it was shown that next to the accumulation problem, the concentrations of Cu and Pb may surpass the standards for receiving waters during storm events. Treatment of the storm water from separate sewers would technically be possible but economically not feasible and contradictory to sustainable concepts.

Decentralized storm water infiltration

For the studied case some assumptions on the hydraulic conductivity of the soil and on the design of infiltration systems were made. Assuming an average low soil permeability with a k-value of 10^{-5} m/s and rain events with a recurrence period of 2.5 years the necessary infiltration area amounts to 6% of the runoff area. This leads to 2.8 m^2/inhabitant and 3.8 m^2/inhabitant of required infiltration surface for roof runoff and road runoff, respectively. From Table 6, the specific loads which can be expected to pollute the infiltration sites are visible. In the scenario of full achievement of decentralized infiltration all roof and road runoff will be infiltrated, therefore, also the presently not sewered storm water was taken into account.

Table 6. Heavy metal loads in g/inhabitant per year in the decentralized infiltration system

Loads in g/inh·a	**Cd**	**Cu**	**Pb**	**Zn**
Input drainage system sewage				
Domestic wastewater	0.015	4.0	2.5	20.0
Industrial wastewater	0.025	3.1	1.3	20.7
Unpolluted water	0.003	0.1	0.1	0.6
Input storm water drainage				
Road runoff	0.112	5.9	11.4	26.2
Roof runoff	0.036	9.6	6.2	19.7
Loads to the receiving water				
Treatment plant effluent	0.017	1.7	0.7	14.1
Loads into solids				
Sewage sludge	0.026	5.0	2.7	33.0
Grit chamber	0	1.0	0.8	3.2
Total	0.026	6.0	3.5	36.2

In decentralized infiltration systems, it is the soil of infiltration sites which is mainly affected by the pollution contained in the storm water runoff. In comparison to the natural infiltration process, the artificial infiltration concentrates the runoff of a certain drainage area by a factor of 5-100 depending on infiltration structure and soil permeability. Taking into account that heavy metals accumulate mainly in the top layers of an infiltration site, the accumulation rates of these substances increase by a factor of the same magnitude. While the accumulation on agricultural land takes hundreds of years to reach critical values, the same phenomena take place within 3-20 years in infiltration sites depending on the pollution level of the runoff water (roofs, roads). In surface infiltration systems through humus layers the top 20 cm and in sub-surface infiltration shafts layers of about 100 cm can be assumed to serve as soil matrix for heavy metal accumulation. Based on these assumptions the annual accumulation rates per weight of soil were calculated. The results are shown in Table 7 and reveal the extremely rapid increase of the heavy metal content in the soil.

Considering the already existing heavy metal content of urban top soils, the time to reach present soil standards for agricultural land is within 1 to 5 years. At the present time the affected soil volume is usually small and is in most cases not used for agriculture. However, increasing accumulation and saturation of top soil layers may lead to a yet unknown dispersion of the heavy metals and other pollutants.

Table 7. Heavy metal accumulation rates in g/ton of dry solids per year in surface and subsurface storm water infiltration systems for roof and road runoff, existing pollution of top soils and soil standards

	Surface infiltration systems		**Subsurface infiltration shafts**		**Pollution of top soils**	**Present soil standards**
	Roof runoff	**Road runoff**	**Roof runoff**	**Road runoff**		
	g/t DS·a	g/t DS·a	g/t DS·a	g/t DS·a	g/t DS	g/t DS
Cd	0.02	0.10	0.004	0.02	0.38	0.8
Cu	11.2	5.2	2.3	1.0	33	50
Pb	7.4	10.0	1.5	2.0	48	50
Zn	23.5	23.0	4.7	4.6	81	200

In order to demonstrate that existing infiltration structures are effectively straining and adsorbing heavy metals in large amounts, two infiltration systems for road runoff were investigated in detail (Mikkelsen *et al.* 1996). In one case the storm water is infiltrated through the surface next to the road shoulder while in the other one it is infiltrated in shafts of about 3 m depth along the side of the road. Heavy metal profiles were analyzed to assess the extent of soil contamination and tests of the leachability of the accumulated metals were performed to allow some conclusions concerning the mobility and the eco-toxicology of the pore water in the soil. In Figure 4, the accumulated heavy metals are shown as a function of depth and reveal heavy metal concentrations which are in all cases more or less severely above the present guidelines for agricultural soils. The results clearly confirm the expected accumulation over a period of about 20 years in a locally limited soil volume.

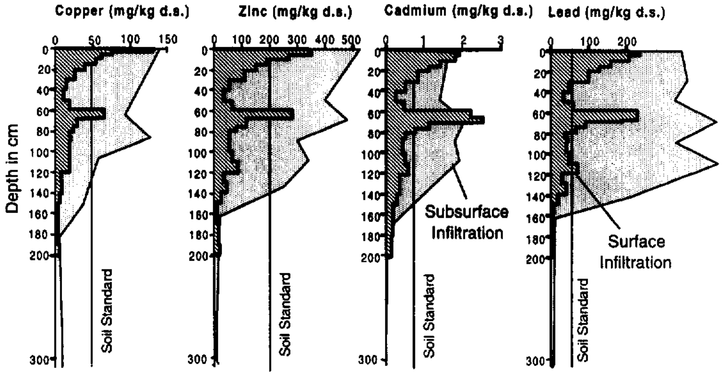

Fig. 4. Heavy metal profiles in surface infiltration pits and in subsurface infiltration shafts for road runoff permeation (Mikkelsen *et al.*, 1995)

COMPARISON OF THE ALTERNATIVE DRAINAGE SYSTEMS

Although most sophisticated technologies for water transport and treatment are applied, it becomes obvious that heavy metals do not just disappear from the environment. Whatever system we are dealing with the metals accumulate in the environment. As long as we do not find further ways of decreasing the mainly diffuse emission of heavy metals, the question remains where do we want the heavy metals to accumulate to cause the least environmental hazard. In the three discussed drainage systems the hazards evolving from heavy metal pollution in runoff water, in domestic and industrial effluents are located in different environmental compartments. As an example the relative mass flow of Cu is shown for the three systems in Figure 5. The results clearly demonstrate that with combined sewer systems it is primarily the sludge which accumulates heavy metals from the different sources. If the sludge is used in agriculture a slow but very diffuse accumulation of metals - in addition to the accumulation by rainfall and fertilizers - will result in a longterm deterioration of the soil quality. In a similar way, the accumulation of heavy metals from runoff waters which are separately discharged into surface waters in separate systems lead to a slow but diffuse accumulation of heavy metals in river and lake sediments giving rise to eco-toxicological problems. Finally, the rapid but locally limited accumulation of heavy metals in infiltration plants is considered to be the most appropriate solution. If the accumulation is controlled by a strict registration of all infiltration sites in certain areas and eventually by introducing porous layers with special adsorption capacities for heavy metals and other pollutants which can be easily accessed, the environmental hazard can be minimized. This way, the advantages of storm water infiltration can be combined with the presently best available solution for heavy metal accumulation.

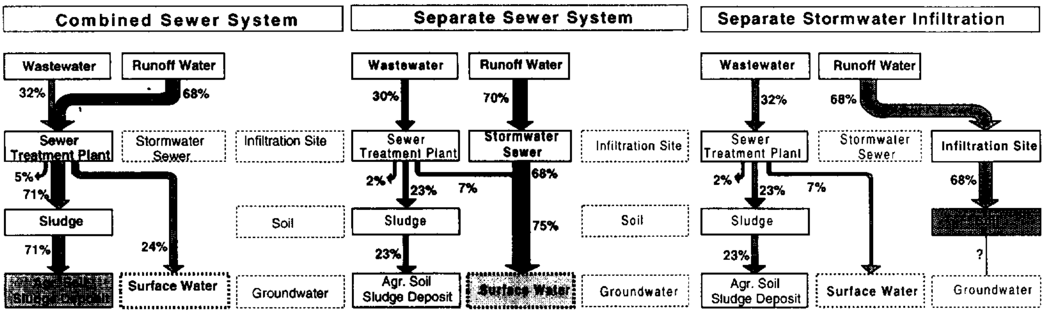

Fig. 5. Relative mass flow of copper in different urban drainage systems.

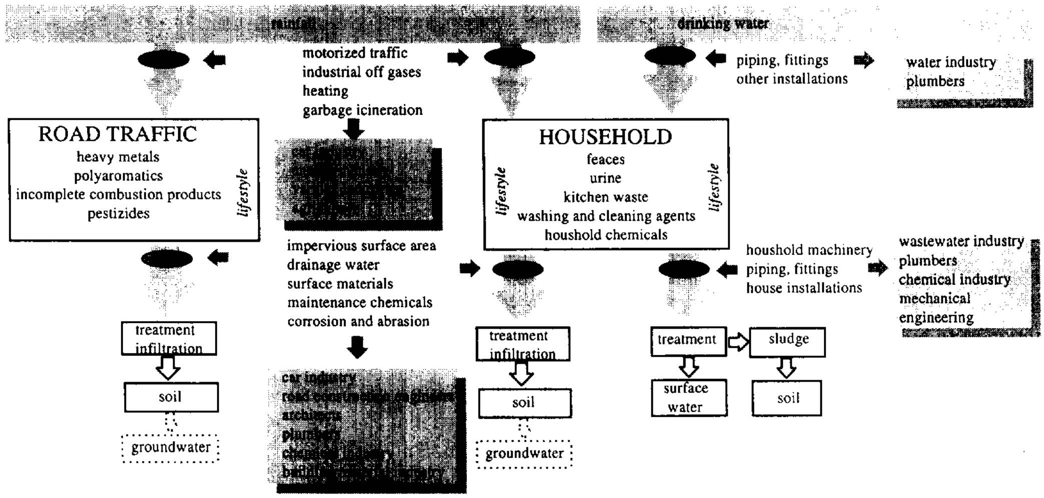

Fig. 6. New partners of urban drainage engineers to reduce diffuse pollution at the source.

CONCLUSIONS

Positive changes of urban drainage systems towards sustainable concepts such as the introduction of storm water infiltration or reuse are hampered by diffuse pollutants from air pollution and surface materials in contact with the runoff waters. Above all, heavy metals are present in significant amounts in runoff waters and turn basically water and energy conserving installations into undesired accumulation sites of hazardous matter. It becomes clear that the input of diffuse heavy metal pollution into the aquatic environment can only be cut at the source. But this will require new efforts in various professional activities not traditionally related directly to environmental engineering. New relationships of the sanitary and environmental engineering society have to be established to architects, to plumbers, to car and road construction engineers, to material technology specialists and other groups which are somehow related to the utilization of heavy metals and other diffuse pollutants which end up in undesired emission to the environment. In addition, material technologists are requested to propose and find appropriate materials to replace technical elements and surface materials in contact with water which are of a basically hazardous nature. Figure 6 shows a picture of the network between environmental and sanitary engineers and other professional groups which has to be formed in order to successfully reduce heavy metal mass flows in urban water systems.

The abatement of diffuse heavy metal pollution at the source will probably require some decades. Information and education of professional groups concerning the pollution of runoff water by certain activities or products, the acceptance to change activities or products, the search for new materials with more sustainable characteristics, and the appreciable lifetime of the presently used materials are some reasons which turn the reduction of heavy metals in storm water runoff into a longterm step-by-step process. Therefore, measures should be taken today, and parallel to the efforts at the source, which are suited to fixate heavy metals and other pollutants in small and controllable volumes. This is best achieved by combining the advantages of separate sewer systems with decentralized storm water infiltration and the introduction of porous adsorbant materials in artificial recharge sites. Suitable media for this purpose are the subject of present and future research (Sansalone, 1996).

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