Risk of traffic induced contamination of the water cycle: assessment of urban snow and soil in the Tyrolean region

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Abstract

In this paper two projects accomplished in Tyrol dealing with the environmental impacts of contaminants are presented. In both investigations heavy metals Cu, Zn, Pb and Cd originating from human activity were measured. The first project, conducted in the city of Innsbruck, aimed at measuring pollution of roadside snow and estimating the impact of snow management practises on environmental quality of rivers. Various locations with low and high traffic densities were investigated. It was found that the snow contained rather high concentrations of heavy metals and that traffic is not the dominant source for cadmium pollution. The second project dealt with the investigation of infiltration swales at supermarkets' parking lots in Tyrol. On site infiltration of storm water to reduce hydraulic sewer loads is not only common practise but even mandatory from a legal point of view. Measurements of pollutant concentrations accumulated in the soil material of the swale were conducted as well as hydraulic tests. In contrast to snow management issues, the focus here was on the long term aspects dealing with life expectancy of swales that is applicable with respect to hydraulic and contaminant removal capacity. Since measurements provide only a snapshot, mass balance estimates were made to provide a complete picture. Although the approaches are facing substantial uncertainties, they provide an estimate of upper and lower limits. Still, to gain sound and region-specific results, extended investigations would be required.

Keywords: heavy metals, infiltration swale, snow disposal, snow pollution, soil contamination, stormwater

1 Introduction

The impacts induced by pollutants gained importance during the last years. Heavy metals in urban areas, for example, are known to severely affect human health and environmental quality (Dallinger & Berger 1992, Hough et al. 2004). In both investigations heavy metals Cu, Zn, Pb and Cd originating from human activity were measured.

The storm water runoff from streets and parking lots frequently carries significant loads of heavy metals (Barraud et al. 1999). These loads result from traffic and enter the water cycle via atmospheric deposit, snow melt or precipitation. Urban snow melt water can contain higher concentration of pollutants than stormwater runoff (Westerlund & Viklander 2006) due to the accumulation of substances during the retention period of the snow. In northern countries (e.g. Scandinavia and

North America) the problems caused by snow pollution have been investigated with particular emphasis (Viklander et al. 2003).

Infiltration devices as one final recipient have to ensure sufficient drainage of storm water as well as sufficient retention of the associated pollutant loads. In Austria it is even mandatory to infiltrate rainfall runoff on site and numerous infiltration devices at parking lots were installed throughout the past years. The design of infiltration devices is regulated by standards such as ATV-DVWK A138 (2002) or ÖWAV-Arbeitsblatt 35 (2003), which are predominately based on hydraulic considerations. Whereas infiltration devices for highway runoff are well covered in the literature (e.g. Dierkes & Geiger1999) devices at parking areas are not.

The objective of the first survey was to quantify some of the most important pollutants in urban roadside snow in an Alpine region and to assess their potential impact on receiving waters. It was carried out at main streets of the city of Innsbruck in Austria. The second study investigated not only the pollution of the runoff itself but also its effect on the soil material of infiltration swales from parking lots in and around Innsbruck. Permissions for the operation of infiltration swales given by legal authorities are usually limited to a certain period of time. Proper operation of those devices is assumed to be approximately 15–25 years. Therefore, the investigation attempted to have a closer look at the hydraulic and pollutant removal capacity of infiltration swales during their lifetime.

The measurements can provide only a temporary snapshot. To provide a complete picture, additional mass balance estimates based on the measurement results were made. Although the approaches are facing substantial uncertainties, they allow estimates of what can be expected.

2 Methods

In the following a brief overview on the sampling methods and the applied mass balances is given. Details on the laboratory methods can be found in Achleitner et al. (2007) and Engelhard et al. (2007).

2.1 Snow sampling

Several sampling points at roads in Innsbruck were chosen where high pollution was expected (figure 1). One sampling point ("urban reference") was chosen as a reference for deposition of atmospheric pollutants only. Further sampling points were chosen directly at streets: one in a residential area ("low traffic") and four at main streets of Innsbruck ("high traffic").

The snow samples were collected on five different days in January and February 2006. Per sampling event only one sample was taken at each site. The roadside snow samples were highly affected by human activities (e.g. ploughing). Therefore the samples were taken from different snow heap depths and locations to get representative samples. The samples were analysed for the concentrations of copper, zinc, cadmium, lead, chloride and suspended solids.

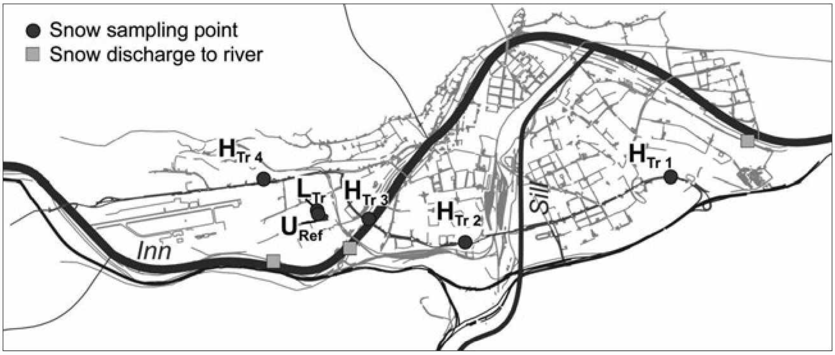

Figure 1: Location of snow sampling points in the city of Innsbruck (U_{ref}: Urban reference, L_{Tr}: Low traffic, H_{Tr}: High traffic).

2.2 Soil sampling at infiltration sites and insitu tests

For this investigation eleven parking lots of supermarket chains in the region of Tyrol equipped with surface infiltration devices were chosen (see figure 2a). The sites differentiated mainly with regard to their period of operation (2–10 years) and to a minor extent with regard to the parking lot size and the mean daily traffic load (620 to 800 vehicles per day). Figure 2b and c illustrate the soil sampling procedure using samples from different locations and depths of the swales. At each site, three locations A, B and C along the swale (figure 2b) were used. In addition one reference sample not subjected to surface runoff was taken from the parking area. The soil samples were analysed for heavy metals (Cu, Zn, Pb and Cd). The hydraulic conductivity was tested in-situ with a double ring infiltrometer test (ÖNORM L1066 2008).

2.3 Estimation of pollutant loads from snow disposal into the Inn

In the city of Innsbruck snow is commonly ploughed to the roadside. If no place is available, snow is collected, transported away by lorry and directly tipped into the river Inn, e.g. snow loads of approximately 30,000 lorries in the winter season of 1999 (Weger 2003). To estimate the impact of this practise on the river, it was assumed that during the winter season 2005/2006 the same number of lorry loads was discharged to the Inn and that the ratio of snow disposal from areas with high traffic density and areas with low traffic impact was 70:30 (this ratio was chosen because snow is cleaned primarily from highly travelled streets whereas the snow often remains until melting at streets of lower priority).

2.4 Estimation of pollutant loads to infiltration swales

The focus here was on the life expectancy of swales, which is – within this work – defined by the time until pollutant accumulation (here heavy metals) exceeds certain standards. As no specific guidelines are available, the Austrian guideline for land

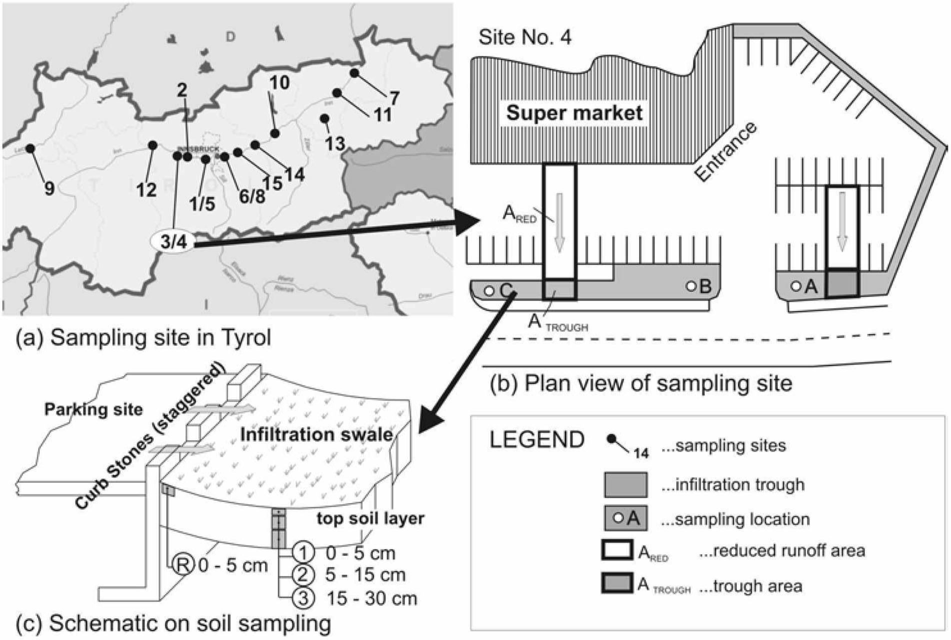

Figure 2: (a) Selected sampling sites in Tyrol, (b) plan view on sampling site and (c) schematic on soil sampling (1, 2, 3 = mid samples, R = side sample).

filling (BGBl. Nr. 146/1996, 2004) is applied. Concentrations in soils are limited in such a way that they are suitable for land filling as excavation material.

For balancing contaminant masses, the pollutant concentrations in the runoff were needed. Within this work, quality parameters of storm water were neither measured at the long term nor for single events. Instead a literature review was made showing a wide range of heavy metal concentrations found in street runoff (see table 1). Thus, already the "input" side provides a large spectrum of possible magnitudes.

The scenarios defining upper and lower boundaries were used to estimate the life expectancy of an infiltration device. Considering the geometry of the parking areas (see figure 2b) as well as annual rainfall quantities, the annual accumulated loads were estimated. This was then extrapolated for current operating time of the swales and their expected lifetime of 15 years.

Table 1: Heavy metal concentrations in surface flow of streets and highways.

Cu [mg/l]	**Pb [mg/l]**	**Zn [mg/l]**	**Cd [g/l]**	**Source**
0.017–0.280	0.010–0.311	0.166–1.940	0.30–6.40	(Welker & Dittmer 2005)
0.108/0.115	0.311/0.318	0.603/0.478	6.40/5.30	(Boller 2004)/(Boller 1996)
0.080	0.004–0.060	0.800–3.00	0.50–7.60	(Dierkes & Geiger 1999)
0.001–0.054	0.001–0.200	0.050–1.460		(Barbosa & Hvitved-Jacobsen 1999)

3 Results

3.1 Heavy metals in snow deposits

Figure 3 shows the mean values and standard deviation of the heavy metal concentrations measured in the snow samples of each sample category. The mean concentration of copper at the low traffic density site, for example, is only about half the value of the mean copper concentration at the high traffic density sites (see table 2). Zinc concentrations were also highly elevated at high traffic density sites as well at the low traffic density site. A similar allocation was found for lead values. For cadmium even the concentrations found at the urban reference site were in the same range as concentrations measured at the low and high traffic density sites. For all heavy metal concentrations measured, high standard deviations were found for samples collected at high traffic density sites.

Compared to the heavy metal concentrations in runoff from streets referred in the literature review of Welker & Dittmer (2005), the mean metal concentrations measured in the snow roadside samples of the present study (i.e. the low and high traffic density sites) are mostly at the upper end of the range. For copper, even the mean concentrations found in the roadside snow samples of the present study are above the ranges referred in the literature.

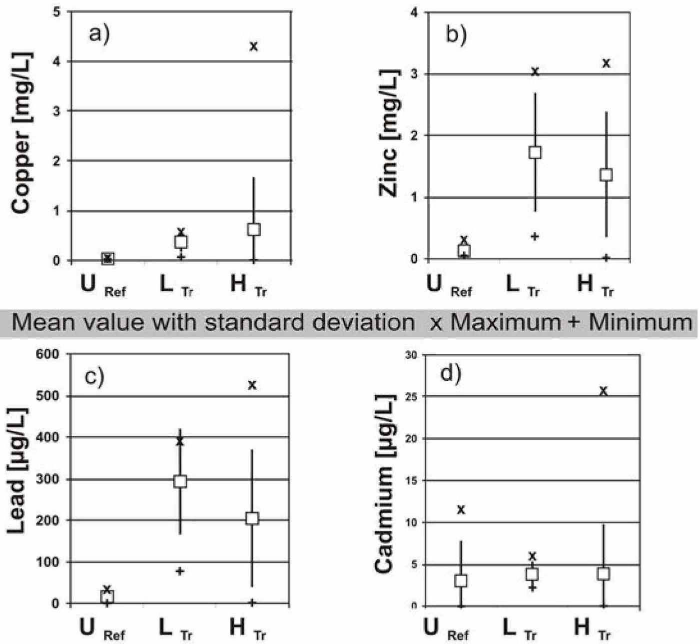

Figure 3: Mean values with standard deviations (lines) and ranges (minimum and maximum values) of Cu (a), Zn (b), Pb (c) and Cd (d) concentrations of snow samples. Abbreviations: Uref: Urban reference, LTr: Low traffic, HTr: High traffic.

Table 2: Mean value of pollutant concentrations of snow samples and numbers of analysed samples (No.).

	No.	Cu (mg/L)	Zn (mg/L)	Pb (µg/L)	Cd (µg/L)	Cl^- (mg/L)	SS (mg/L)
Urban reference	5	0.02	0.13	16	3.01	8	12
Low traffic	5	0.36	1.73	293	3.76	237	289
High traffic	20	0.63	1.37	205	3.87	274	959

3.2 Heavy metals at infiltration sites

It was expected that concentration levels decrease with the infiltration depth and that the majority is retained near the surface. This could not be proven true for all sampling points. Still, relatively low concentrations of heavy metals were found compared to limits defined for land filled excavation material. The pH values measured (7–9) are high for all sites, indicating a low mobility of heavy metals. Measurements of pH were based on methods defined in the DIN EN 12176 (1998) using distilled water for soil mixing.

No trends were found between heavy metal concentrations and the site parameter age or permeability (see e.g. for copper figure 4). Similar age and hydraulic permeability did not correlate. Thus, it is not proven that swales with increasing age may be silted up and then – potentially – no longer meet the required hydraulic capacities.

3.3 Mass balance estimates for snow and pollutant flux impacts on the environment

The pollutant concentrations of the urban roadside snow found in the present study varied over a large range. Consequently, it was difficult to correctly estimate the pollutant loads discharged into the river Inn in Innsbruck by snow disposal activities. Therefore, estimations were made for mean loads as well as for best and worst cases. The results (expressed as kg or tons per winter season) are summarised in table 3.

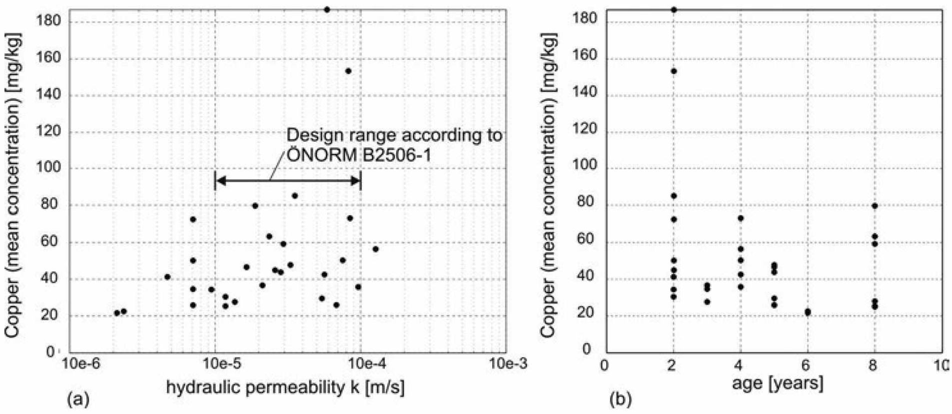

Figure 4: Concentrations of Cu versus (a) hydraulic permeability and (b) age of the facility.

Table 3: Estimation of pollutant loads (expressed as kg or tons per winter season) discharged into the river Inn during the winter season 2005/2006, shown for the different heavy metals (Cu, Zn, Cd and Pb), as well as for chloride and suspended solids (SS).

Cu (kg)	Zn (kg)	Cd (kg)	Pb (kg)	Chloride (tons)	SS (tons)
79 (4–458)	212 (17–451)	0.6 (0.1–3)	33 (3–70)	38 (2–412)	109 (0.5–412)

The results are based on the assumed disposal ratio of 70:30 for snow from high and low traffic density areas. The obtained results from the best and the worst cases differ widely from each other. Nevertheless, it can be expected that considerable amounts of heavy metals and chloride are directly discharged to the river due to road maintenance activities. Hence, an adverse impact on the river water quality and ecology cannot be ruled out.

3.4 Mass balance estimates at infiltration sites

In the same manner upper and lower boundaries for total accumulated loads in the swale soil materials were assessed. The implied assumption was that heavy metals accumulate in the soil material since high pH values were found throughout all sites. The calculated concentrations (including the worst case scenario) do not exceed the measurements in most cases (see figure 5). As possible reason the dominant role of geogenic background of the soil materials, dry depositions or a combination of both was identified.

The measurements (C_m) in figure 5 are corrected using measurements from the reference locations (C_o). The implied assumption that the soil material used for construction was the same one does not hold true for all sites. At site No. 15 C_o was found to be larger than C_m. Finally, the annual loads were extrapolated for 15 years of operation. For copper legal threshold values were only exceeded at one site and

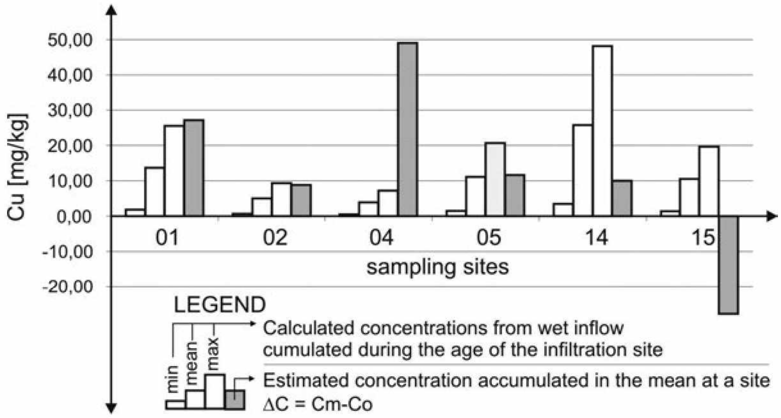

Figure 5: Comparison of wet deposition values of cumulated concentration (estimation and measurements) for different sites.

under worst case conditions after 15 years lifetime. Similar findings were made for the remaining heavy metals.

4 Conclusions

The present investigation of pollutant concentrations in snow has shown that roadside snow in Innsbruck contains considerable amounts of heavy metals, chloride and suspended solids. It was found that the pollutant concentrations in the snow samples were rather higher than the concentrations in stormwater runoff found in literature. Huge amounts of snow are being dumped into the Inn and consequently, the pollutant loads reaching the river with the snow mass can be expected to be considerably high. However, to verify an impact, further investigations would be necessary.

Beside rivers, infiltration devices constitute the second sink of pollutants from surface runoff. The analysis of soil samples from different sites showed pH-values indicating a low mobility of all heavy metals included in the tests. Thus, together with the hydraulic permeabilities observed, a retardation of the majority of loads is expected. No violations of limit values were observed at the swales current period of operation. The observed pollutant concentrations in the infiltration swales' soil showed large variations regardless of the location. Extrapolations made for lifetimes of 15 years showed only rare limit violation and only under extreme conditions. Soil concentrations seem to be strongly influenced by background concentrations. Still, the stipulated 15 years operational lifetime appears to be feasible, based on the applied criteria.

The measurement of pollutant behaviour over time, like accumulation, in snow as well as in soil material would require more intensive measurements. For snow investigation the samples would need to be collected at shorter time intervals and with an accurate assessment of the sampling conditions (changes in snow bank size, road maintenance activities, etc.). This is of special importance to correctly assess the mass balance of pollutants associated to snow . Further, it is desirable to concretise the currently only vague statements with regard to life time expectancy for local infiltration devices. Continuous measurement of only the soil material as well as a full mass balance of snow, water and soil concentrations are worthwhile for covering the pollutant cycle for short- and long-term aspects.

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