Chapter 4
Urban Soils in the Vadose Zone

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4.1 Introduction

Between the soggy ceiling of the ground water aquifer and the uppermost interface of earth and air is the unsaturated space of soil particles and pores invisible to most surface dwellers – the *vadose zone*. In cities, this space can be frozen in time under buildings and sidewalks, and contaminated with various kinds and concentrations of polluting substances. With more than 50% of the world's population living in cities as of 2007, research on the composition, function and dynamics of urban soils is of utmost importance for urban ecological questions as well as the for the well-being of city dwellers world wide. Even before the 50% demographic benchmark, interest in anthropogenic soils began stirring in Germany in the 1970s in Berlin and Essen (Burghardt 1995; Blume 1975). At that time, research concerns revolved around the proper classification of soils in urban areas and the dilemma of restoring and re-using former industrial sites. From the 1980s until the beginning of the 1990s, pollution of urban soils with organic and inorganic contaminants became the focus of many studies (Thornton 1991; Lux 1993; Radtke et al. 1997). Since then, research on urban soils has substantially broadened. The *BMBF* (Federal Ministry of Education and Research) project "Evaluation of Urban Soils" from 1993 to 1996, for example, included groundbreaking work on the chemical, physical and biological properties of anthropogenic soils, involving major soil science institutions from the universities of Kiel, Essen, Hohenheim, Halle, Rostock and Berlin. Results are presented in Blume and Schleuss (1997).

Despite growing interest in urban soils, not much is known about the interrelated processes within the vadose zone. The following contribution seeks to address this knowledge gap by highlighting the results of studies conducted from 2001 to 2010 by two research groups on urban soils. The material introduced here has been specifically chosen to give a broad and relevant overview of urban soils, their

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associated uses and potential risks. Key issues include the dynamics of water and soil materials at urban locations under consideration of spatial heterogeneity, organic soil substance, and soil-biological transformation processes (*DFG research group Interurban, Water and Organic Matter in Anthropogenic Soils: Dynamics and Processes*) as well as the hydraulic and sorption properties of urban soils under consideration of land use and soil management *(DFG-GRAKO graduate research group, Perspectives on Urban Ecology*).

We start out by presenting some general ideas on urban soils and several guiding principals in their evaluation. We then examine the properties and utilization of several urban soils, their influence on the vadose zone and finally their cultural significance for urban societies. The first section addresses soil material prevalent in nearly every city of the world – rubble, and in the case of Berlin, massive deposits of building rubble from WWII. What is the physical, chemical and biological nature of rubble as a soil substrate? Aspects of soil development on rubble, hydrological behavior and the associated release of sulphur are closely examined in two locations – a former urban brownfield at Lützowplatz and a gradient downslope of Teufelsberg, the highest slag heap (114.7 m) in the greater area of Berlin.

The second section addresses areas that have been partly sealed because of building development. What is the impact on the local water balance and to what extent can partly sealed soils fulfill their filter function? Furthermore the question is taken up as to whether it is justifiable to treat these areas with herbicides (Roundup) to get rid of the vegetation in the cracks of the sidewalk. The third section discusses roadside soils. As before, changes in soil properties due to road construction and long-term traffic are a focus of attention. We examine the water balance of roadside soils and the long-term relocation of heavy metals at the AVUS Highway in Berlin, the oldest motorway in the world.

Finally, we consider the task of communicating the function and fragility of the vadose zone. While fundamental research on the properties and dynamics of urban soils is the main focus of our efforts, we are also concerned with the greater understanding and appreciation of soil physical and hydrological concepts. In the final section, several public outreach projects are introduced as examples of innovative communication. They specifically address issues featured in the other parts of this chapter, demonstrating how representatives from the arts and humanities are confronting challenges such as soil sealing, storm water run-off and contamination.

4.2 Characteristics and Evaluation of Urban Soils

Urban soils are distinguished from agricultural and natural soils by a range of anthropogenic factors such as the presence of human artifacts and contaminants, alkaline pH, high black carbon content, high bulk density, low soil moisture, warmer soil temperatures, and a relatively young stage of pedogenetic development. The heterogeneity of urban substrates and their constituents is much greater than in natural soils. The same is true for disturbances, such as compaction or mixing of horizons. Even more importantly, the pollutants in the substrates and the immissions themselves often have very heterogeneous compositions.

Given this heterogeneity, quantitative information on hydraulic properties and their impact on the groundwater is required for the evaluation of urban soils in the vadose zone. This is especially the case when future management targets come into play. The evaluation of soil water balance, sorption behavior, and associated physical aspects, for example, plays an important role in urban and environmental planning decisions. As we learn more about the physical properties of urban soils, we also uncover remnants of past planning schemes and can use this integrated knowledge for future land use management.

Pollutants in older, densely populated neighborhoods, for example, are often a consequence of unregulated waste management from times past. Specific contaminants might include combustion residues of heating processes, feces and refuse that were disposed of, in, and on the surrounding soils. Waste materials associated with certain manufacturing and production processes also accumulate on industrial and commercial sites due to leakages and accidents (Blume and Schleuss 1997). While many of these sites are no longer in use, a number of papers and projects have examined the contamination of urban soils by organic and inorganic pollutants. Atmospheric emissions represent another source of excess nutrient inputs in the soil. And research on the impact of animal excrements (dog urine) on the vitality of urban trees has also been made available (Balder 1994).

While the transport processes of such contaminating substances are influenced by the same factors as those found in natural soils, their characteristics are quite different. Important distinctions are sealed and partly sealed areas, typically characterized by concentrated infiltration, soil compaction, and the occurrence of technogenic (as opposed to geogenic) materials. Excessive exposure to nutrients and pollutants causes surface contamination of sealed and partly sealed areas. After a period of time, these contaminants are then conveyed through the soil substrate via the rainwater through seams and open pore spaces into the subsoil and vadose zone, or directly into the canalization.

The degree of pollutant fluctuation can vary greatly within a specific location and unit of soil. Fluctuation depends foremost on the type of substrate (e.g., debris, building rubble, ashes, slag and domestic refuse) and the source of the pollution, such as effluents, sewage sludge or depositions from traffic (Renger and Mekiffer 1998; Hiller and Meuser 1998; Kocher et al. 2005; Mekiffer 2008). Mekiffer for example, has shown both (1) that total contents of heavy metals in general have a wide span in urban soils, and (2) that regular ranges of content or depth gradient specific to certain substrates are not recognizable.

This means that the mobility of heavy metals from technogenic soil substrates can differ greatly for the same total contents. Non-point pollution inputs with a diffuse distribution can come from industrial, traffic and domestic fuel immissions. Point contaminations, on the other hand, are often a local, i.e. a discrete result of industrial use, waste disposal or sewage farms. Despite this variability, a preliminary risk evaluation into the existence and type of pollutants in urban soils can be partly achieved with the help of observable on-site findings. Meuser (1996) developed a substrate key that allows a first identification and diagnosis of soil-extrinsic admixtures as well as guidelines for risk assessment. The following site factors are taken into account when evaluating the mobility of heavy metals and their potential risk to the groundwater:

- Substrate materials
- Depth of groundwater level
- Mobility determining soil characteristics (e.g., pH-value, clay and humus content, DOC, redox potential)
- Source and type of pollutants (e.g., lead, cadmium)
- Interaction with other cations or electrolytes
- Kind and duration of site use (time period and length of use, time since use discontinued).

Another important question in the urban context concerns the consequences for the local water balance due to increased sealing through buildings and roads. In the highly industrialized countries of Europe, America and Asia, sealed and developed areas take up a vast percentage of land surfaces. For example in Germany over 12% of the total land area is already sealed, with a continuing upward trend. In addition to aspects concerning the drainage of sealed surfaces, we know that sealing can contribute to the generation and aggravation of heat stress. Because of this, green spaces in urban environments fulfill an important climatologic balancing function. The question arises as to whether we can estimate the actual evaporation for different degrees of sealing and furthermore whether and how we can strategically use this knowledge in urban planning and development.

4.3 Soils on WWII Rubble

4.3.1 Introduction

A common soil substrate in cities across Europe and the globe, rubble often makes up a large component of the soil hidden beneath parks and private gardens, sidewalks, and other public places. When the last smoke cleared on May 8th, 1945, much of Europe lay buried in rubble. Approximately 400 million m^3 of debris was left in the wake of World War II in Germany alone, due to the bombing of residential and industrial buildings (Blaum-Jordan 1947). In Berlin, about 30% of the residential buildings were destroyed completely, and another 45% partly razed (Arndt 1947). In the past 65 years, neighborhoods have been rebuilt and parks reforested, obscuring traces of approximately 75 million m^3 of debris deposited throughout the city.

The soils we discuss in this section contain large amounts of fired brick and mortar. They developed on WWII rubble or on century-long accumulations of debris due to the cyclic demolition and reconstruction of houses. The soil type

Fig. 4.1 Urban soil with a rubble layer from WWII in 30–60 cm depth

developing on rubble material from buildings is usually a Pararendzina because of the calcareous parent material. Figure 4.1 shows a typical soil with rubble material in the subsoil. The nature of rubble influences the physical, chemical and biological properties of the soil. It also affects the quality of water percolation. For example, the water budget may be altered due to the gradual release of sulphur from the mortar or other technogenic substrates (ashes, coal) that can be found in various buried materials.

In this section we start out with a discussion on the characteristics of rubble material. We evaluated >50 sites in Berlin with rubble deposits in order to get information on typical site properties. Specifically, we included a soil genesis study by Blume and Runge that analysed a rubble soil development on a former urban brownfield at the Lützowplatz, Berlin in 1978. Finally, we address concerns about sulphate leaching associated with desorption from rubble and other technogenic components we studied along a down-slope gradient on Berlin's largest slag heap, Teufelsberg (Devil's Mountain in English).

4.3.2 Soil Material Properties

Parent material for the pedogenesis of rubble soils comes from different types of building materials, which were constructed and demolished in different ways and at different times. The sorting and disposal of materials also differs from place to place and generation to generation. For our purposes here, we may distinguish between three groups of materials:

1. Metals, ceramics, glass, bitumen
2. Leather, slate, marble, limestone fragments
3. Carbon, organic carbon of the fine earth fraction, inorganic carbon of the coarse fraction

Some basic information on debris soils and their components are listed in Table 4.1.

In most cases soils developed on rubble from WWII have a high coarse fraction (>2 mm). Dominating skeletal components are brick, mortar (including plaster and stucco), slag, ashes and sometimes unburnt coal. The analyzed components are characterised by alkaline pH-values. Seventy-five percent of the samples demonstrate an electrical conductivity of up to 141 μS/cm. This is a first indicator of the slightly saline conditions of the heterogeneous material. Bricks mainly consist of oxygenates from Si, followed by oxygenates from Al, Ca, Fe, Mg, and K. X-ray analysis of bricks showed that the most common minerals are clay minerals (kaolinite, illite, montmorillonite, chlorite), quartz, and carbonates (calcite, dolomite an siderite). At a lower percentage, the bricks contain Fe-oxides (hematite, goethite), sulphates, and sulphides (gypsum, pyrite, markasite). Five to twenty percent of the minerals are X-ray amorphous. Mortar, on the other hand, is characterised by a high amount of silicates (up to 80%). The samples that were investigated showed a lower percentage of Al- and Ca-compounds than bricks.

For ashes and slag, there is a wide range of chemical compositions, depending on the nature of their origin. In soils developed on debris from WWII, for example, ashes from domestic fuel are prevalent. Ashes originating from anthracite coal contain oxides of Si (40–55%), Al (23–35%), Fe (4–17%), Ca (1–8%), Mg (0.8–4.8%), K (1.5–4.5%), Na (0.1–3.5%), S (0.1–2%) and Ti (0.5–1.3%). The most important minerals are quartz, mullite, illite, hematite and magnetite, and sometimes carbonates and sulphates. Slag is of an inhomogeneous composition. It often contains inclusions of other materials such as ashes, molten products and stones.

The release of cations and anions from skeletal components was investigated using the soil water extracted from two different grain sizes of every sample (2–6.3 mm and <2 mm). The release is influenced by the size of the grains, but the dominating factor is their chemical composition.

Table 4.1 Properties of urban soils containing rubble [according to Blume and Runge (1978) and own measurements]

Component	Fraction	C	$CaCO_3$	B	Cu	Mn	Zn	Porosity	Wilting Point	Field Capacity
	Weight%			ppm				Vol.%		
Fine earth <2 mm	60	0.7	10.3	30	100	160	800	40	5	18
Constituents										
Brick	22.4	0	3.0	20	30	500	200	45	17	38
Mortar	12.4	0.1	15.5	10	30	14o	300	34	3	26
Coal		62.0	2.3	3	40	120	9,000	–	–	–
Slag	0.6	6.2	1.7	60	80	1,500	300	–	–	–
Artificial products	2.7	5.3	11.0	70	2,200	900	24,000	–	–	–
Natural products	1.9		n.b.	n.b.	n.b.	n.b.	n.b.	–	–	–

Rubble contains up to 15% $CaCO_3$ and high total contents of trace elements such as Cu, Mn and Zn. However, due to high pH-values, the availability of these elements in the soil solution for plants as well as for the transport into the groundwater is mostly low. Toxic reactions to Zn may be expected after a sharp decrease of pH-value. As long as the pH-value remains high trace elements such as Pb and Cd are not harmful, despite high levels. Because of the high amount of fine pores, the porosity and the field capacity of brick is relatively high.

The available water holding capacity (AWmax) of sites with rubble depends on the size and amount of bricks. As Blume and Runge (1978) have already shown, mostly ranges of 50–120 mm were found. However the origin and manufacturing process of the bricks also plays an important role in the water holding capacity in the pores, as Fig. 4.2 demonstrates. While the traditional loam brick has a relatively high water capacity of >25 Vol%, industrial clay or loam bricks have <20 Vol%. One reason might be the higher burning temperature of the industrial brick material during the manufacturing process. Many bricks, especially those with black color contures, have been burned twice – the first time during their production and a second time during the war because of extremely high temperatures of the fire blast after bombing.

The quantity of plant available water on sites with rubble not only depends on the size and kind of bricks but also on the surrounding soil material. Table 4.2 shows the typical composition of rubble soils with their technosol constituents. From Fig. 4.3 one can see that urban soils consisting of building rubble have an

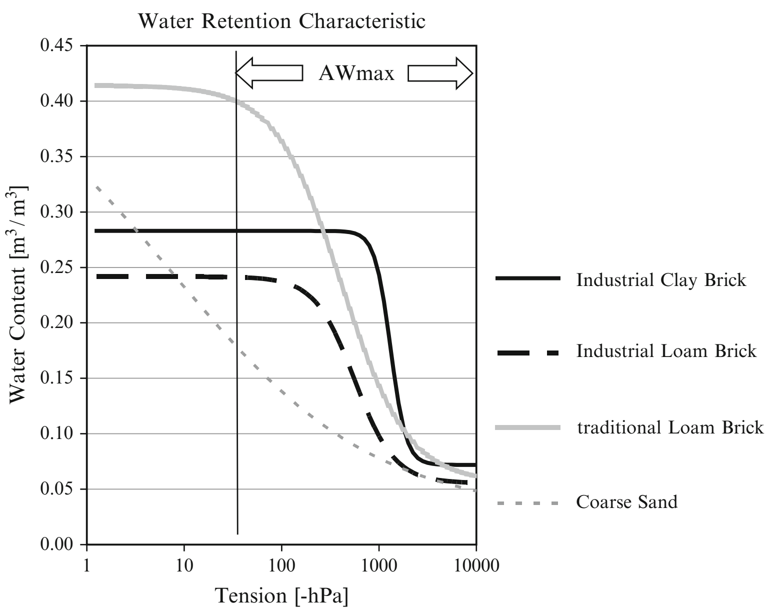

Fig. 4.2 Available water capacity (AWmax) for various bricks

Table 4.2 Debris material and its main technogenic components

Component	Percentage (vol.%)
Brick	2 – 60
Mortar	2 – 50
Slag	2 – 30
Ashes	2 – 50
Glas	2 – 10
Tar	5 – 10
Charcoal	up to 5
Concrete	5 – 10
Soot	up to 2

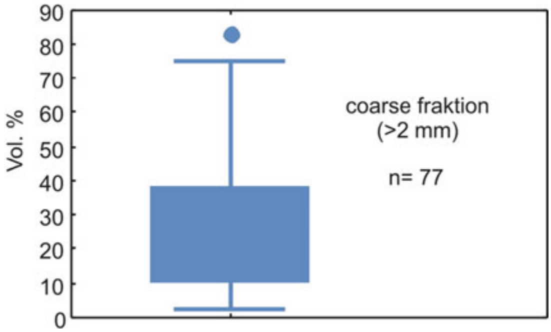

Fig. 4.3 Coarse fraction (>2 mm) of urban soils consisting of rubble

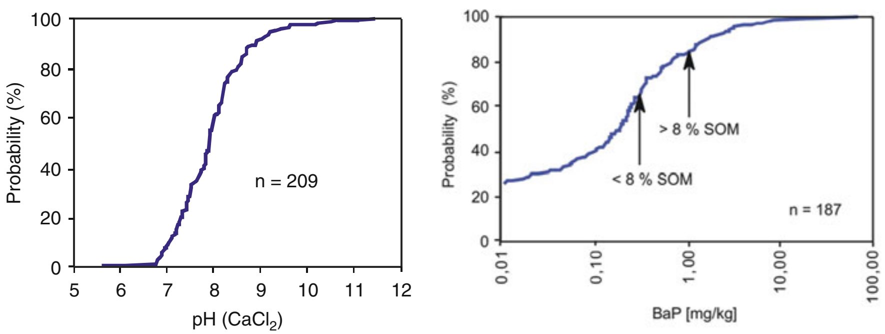

Fig. 4.4 Probability distribution of pH value (*left*) and benzo-a-pyrene (BaP) concentrations (*right*) in urban soils consisting of rubble

average skeletal fraction of 25%, with a wide degree of variance. In some urban soil horizons >80% rubble exists.

The average pH-value of the technogenic rubble substrates lies in the weakly alkaline region, as indicated by Fig. 4.4 on the left. 35% of the samples have a benzo-a-pyrene content that lies above the precautionary limit for soils with humus content of <8%, according to the Federal Soil Protection Act. This is actually less than expected from the manifold effects of combustion on rubble material. The low percentage is suggestive of an inaccurate classification of substrates.

Table 4.3 Characteristic parameters of trace element distributions in rubble soils

[mg/kg]	pH-value	Pb	Cd	Cu	Zn	BaP
Median	7.9	108	0.115	28.05	180	0.183
Mean value	7.96	366	0.66	260.99	478.72	1.096
25 Percentile	7.42	44.3	<NWG	10.8	65.2	0.0048
75 Percentile	8.3	330	0.63	68	590	0.483
90 Percentile	8.9	1,000	1.3	138	1,297	1.5
Maximum value	11.4	7,170	17.2	2,500	4,100	69
Trigger values of the SPA, sand with SOM <8%	–	70	38	72	76	35

SPA Soil protection act of Germany, *SOM* soil organic matter content

Heavy metals such as lead, cadmium, copper and zinc are partly found in high concentrations in rubble soils. The content of Pb, Cu and Zn spans several orders of magnitude in this substrate. In a considerable percentage of samples, these three heavy metals exceed the precautionary limits for the soil type sand according to the Federal Soil Protection Act (Table 4.3). Moreover, the distribution of lead and zinc is characterized by a high proportion of outlying and extreme values.

4.3.3 Soil Genesis

Rubble soils were analysed for the first time by Runge (1974) and Blume and Runge (1978). They analyzed soil samples taken from 1972 to 1974 at the Lützowplatz in Berlin-Tiergarten. The buildings of this site were destroyed during WWII and removed at the end of the war. This resulted in the development of a typical urban wasteland with its characteristic ruderal vegetation. In 1985 the same authors conducted a second soil analysis in order to examine soil forming tendencies. By the end of the 1980s, a hotel and gardens were built on the site of the original study location and today Lützowplatz no longer exists in its open, post-war appearance. After the German unification in 1989, subsequent construction of new buildings and pavements gradually redeveloped the area over time.

One of the first and most important soil forming processes is humus accumulation, or the incremental deposition of organic matter from decaying plant litter, excrement and animal residues. In the 1970s Runge (1974) found 3–6 kg/m^2 of organic matter accumulated in a depth of 10 cm. A comparable soil profile contained 5.2 kg/m^2 more organic matter than its parent material. Recent data have shown an accumulation of 7.6 kg/m^2, which was found at depths of up to 30 cm. The average increase of organic matter amounts to 0.4 kg/m^2 per annum for the first 12 years and 0.2 kg/m^2 per annum for the second 12 years.

The increase in organic nitrogen was even more substantial than the increases in organic matter. In 1972 the profile at Lützow Platz shows an N-increase of 150 g/m^2 in comparison to the parent material, and in 1985 an increase of 210 g/m^2 could be found. For the two time periods this implies a rise of 12 g/m^2 per annum in the first 12 years and 6 g/m^2 per annum for the second 12 years (or 120 and 60 kg/ha per annum). This increase was a result of the N-uptake of soil bacteria in symbiosis with wild-growing black locust (Robinia pseudoacacia) trees. It is also worthwhile to mention that the C- and N-amounts in the upper soil horizon (0–2 cm) were in steady equilibrium after only 12 years. After this period their amounts did not increase anymore (Blume and Runge 1978).

Many urban soils have a low skeletal fraction of rubble in the top 10–20 cm. This may be due to crushing under heavy leveling machines, weathering of mortar and the activity of animals, especially arthropods. The loss of carbonates in the upper soil horizon is partly redistributed in the subsoil. Blume and Runge calculated carbonate losses of 4–5 kg/m^2, an extremely high amount, which was probably caused by the inhomogeneous parent material. The additional loss during the last decade would add up to 40–50 g/m^2 per annum, which is 400–500 kg/ha per annum. According to the authors, soil acidification has not led to any significant consequences because there is still enough free calcium carbonate in all the horizons. Although clay formation cannot yet be proven, it is obvious that through the disintegration and decalcification of particles, more clay and silt is present in the upper 6 cm of the profile.

Urban soils with rubble components usually have a deep, sometimes very deep root system, depending on the size and compaction of stones in the subsoil. The root zone often ends with a compacted rubble layer, which forms a mechanical barrier. For the most part, roots are unable to enter the cracks of bricks and other stones, but nonetheless one can observe a high density of root hairs on the surface of bricks and other rubble components. Due to a high total pore space and especially a high coarse pore volume, the soils are extremely well aerated and drain rapidly. The total water capacity is comparatively high with 300–500 l/m^2 down to a depth of 2 m, even though only 80–120 1/m^2 are available for plants because of dead water in the fine pores of the brick materials. This means that deep-rooted plants and trees, such as the black locust have a sufficient water supply, whereas plants with shallow roots suffer from water shortages. The low humidity and the higher temperature in the inner city increase evaporation and interception. As a consequence water stress may occur occasionally, even for plants with deeper root zones.

The nutrient conditions of the soils studied are generally good. The total and especially available potassium and phosphorus are higher than levels in pure sandy soils in the city. This is still the case even after the high stone fraction is taken into account. The main root zone already shows comparable amounts of available nitrogen to agricultural soils in Berlin (Blume and Runge 1978). The favourable nitrification conditions are indicated by nitrate domination. An additional input of 20–30 kg N/ha per annum through pollution also has to be taken into account. An even higher eutrophication is caused by animal excrements and urine.

Finally, the heavy metals Pb and Cd are also accumulated in the topsoil (Pb 400–450, Cd 0.5–0.6 ppm) due to the deposition of dust in the upper 4 cm and also in a depth of 10 cm (Pb 200–250, Cd 0.3–0.35 ppm). In contrast, B, Cu and Zn-contents are stable or depleted through seepage or plant uptake.

4.3.4 *Sulphate Leaching from Rubble Deposits*

Sulphate concentrations in the upper aquifers of many German cities have been increasing continuously over the last 40 years (Pekdeger et al. 1997). Particularly in the inner city of Berlin, sulphate concentrations exceed precautionary limits set out in the Federal Drinking Water Act. High sulfate concentrations in the groundwater negatively affect the taste of drinking water and enhance oxidation processes, which lead to corrosion of water works infrastructures because of aggressive acids.

Sulphate leached from WWII rubble is among others one important source of sulphate concentrations in the groundwater. Assuming ideal solution conditions in Berlin, only 25% of the sulphur reserve of nearly 75 million tons of WWII rubble, has been solubilized and transported to the groundwater over the last 60 years. With sulphate levels already exceeding threshold levels in the inner city, an incalculable risk of groundwater contamination is developing for several catchment areas in Berlin in the medium term. Figure 4.5 shows sulphate concentrations of the main aquifer of Berlin. High sulphate concentrations furthermore correlate with sites that have high amounts of rubble deposits. Compared to other regions in Germany, the sulphate concentrations in the groundwater of Berlin are exceedingly high (Fig. 4.6) and pose a challenge to future environmental planning and mitigation schemes.

The S-pools of different technogenic materials from urban soils can vary significantly. Slag has the highest S-content, with up to 0.7%. Coal-ashes are also often SO_4-rich. The total S of brick varies between 0.01 and 0.3% and mortar shows

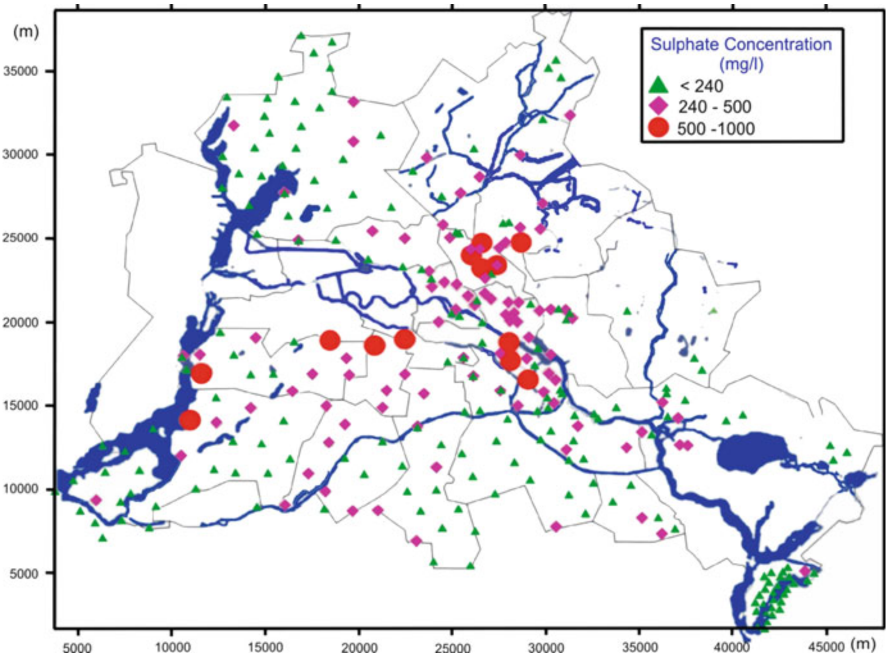

Fig. 4.5 Areas of high sulphate concentration in the main aquifer of Berlin (Pekdeger et al. 1997)

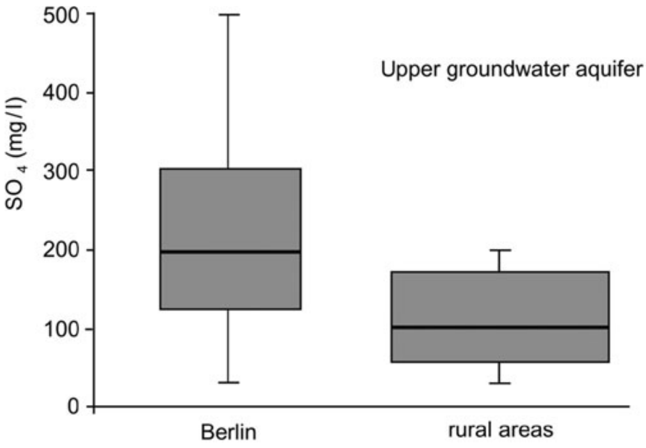

Fig. 4.6 Sulphate load of the surface-near aquifers of Berlin compared to those of rural areas, according to Hannappel et al. (2003)

S-Values between 0.08 and 0.12%. However, 75% of the 54 rubble samples taken from various sites in Berlin had a total S-content of under 0.14%. There was also no significant correlation between total S-amount and water-soluble SO_4. The reason for this behavior can be attributed to the different chemical S bonds in the samples taken. Technogenic components with a grain size of <2 mm have a higher bulk density, but a lower percolation velocity. Furthermore the concentration of ions in the leachate is higher than in the leachate of the coarse skeletal fraction (2–20 mm). Gypsum-rich material (10%) released a constant concentration of SO_4 during the whole experiment, unlike slag-rich material, which initially produced a high concentration of SO_4 in the leachate that decreased rapidly as a function of time. One can surmise that the type and grain size of the technogenic components have a strong influence on the release of SO_4.

In order to get a first impression of the leaching behavior of various rubble materials, soil column experiments were carried out in the laboratory. The advantages of column experiments are (1) controlled boundary conditions and (2) the use of defined soil material in the column. Moreover, one can easily study the effects of particle size of rubble material, various flow rates as well as pH and electrolyte concentration. Figure 4.7 shows an example of such a desorption experiment from a typical sample consisting of high amounts of rubble from WWII. At the beginning of the experiment, very high solute concentrations with >700 mg SO_4/l occur. However, after the sample passed through twice, the sulphate concentration decreased to values of <100 mg/L. These values are unproblematic according to the Federal Water Protection Act.

It appears that only the initial flush of percolation water has a high sulphate concentration. Although water repellent behavior is often observable in sandy urban soils, a long-term prognosis for sulphate concentrations is difficult to make, because only parts of the soil components are wettable and active in the transport of water and solutes.

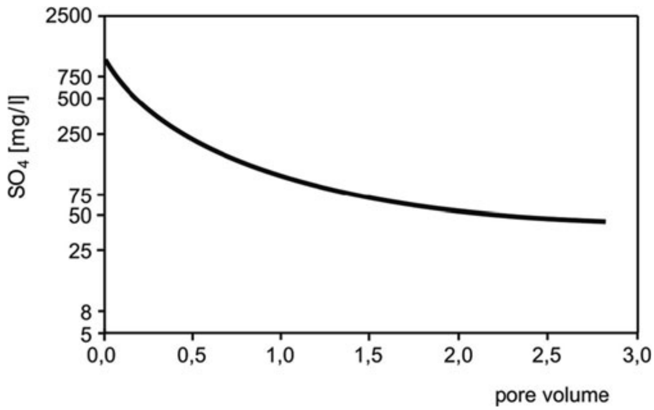

Fig. 4.7 Sulphate concentrations during a leaching experiment, pore volume of 1 means that the solute of the soil volume was percolated (break through) one time completely

4.3.5 Conclusions

Urban soils with rubble material from buildings can be found hidden beneath backyards and sidewalks worldwide. Depending on the amount, depth, compaction, particle size, and type of parent material, rubble can have positive effects on the water holding capacity and nutrient supply for plants. However, we have seen that technogenic composition as well as grain size also has a strong influence on sulphate leaching rates. In the future, research on long-term sulphate desorption may help to predict sulphate transport in the vadose zone. In combination with site-specific information on the active soil water flow parts of the soil, better prognoses can be given (1) to which extent the sulphate concentration will increase in future (Fig. 4.8) and (2) for how many years high sulphate concentrations in the first groundwater aquifer have to be expected.

4.4 Sealed Soils

4.4.1 Introduction

In 1997 Wessolek and Facklam started studying the physical and chemical site characteristics such as texture, heavy metal content, and infiltration rates of partly sealed urban soils. In collaboration with the Berliner Wasserbetriebe (Berlin Public Water Works), they began to investigate the annual and the long-term mean water components of partly sealed urban areas with the help of lysimeters with different surface coverings. In the first phase of the GRAKO research program Nehls et al. (2006, 2008) analysed the physico-chemical behaviour of seam materials. The focus

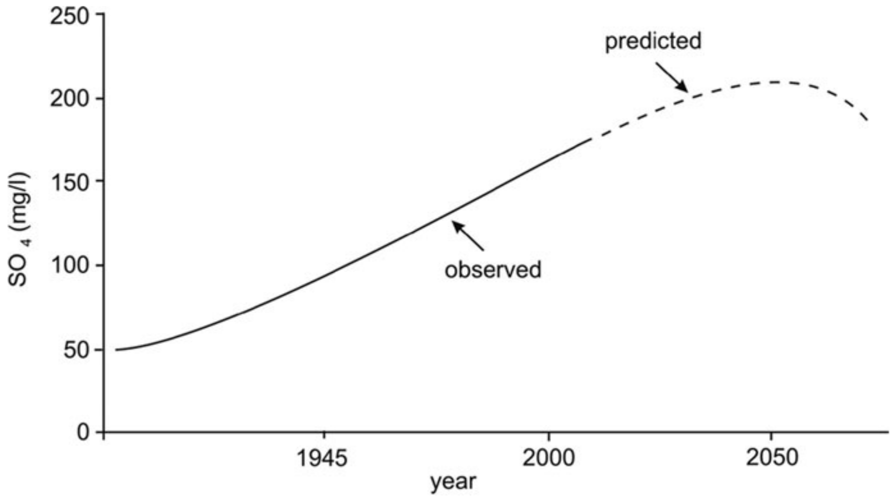

Fig. 4.8 Numerical scenarios help to predict sulphate concentration in the upper aquifer of Berlin (schematically)

lay on the sorption characteristics for trace elements deposited by dust, traffic and other emissions. In the second GRAKO research phase Klingelmann (2009) investigated the sorption behaviour and leaching of the herbicide Glyphosate, which is commonly used for weed control on pavements as a cost-effective chemical method. In the third GRAKO phase Rim analysed the runoff and infiltration behaviour of two different pavements using specially designed weighable lysimeters with a high temporal resolution. In this section interesting results of these investigations will be presented.

4.4.2 Hydraulic Characteristics and Water Components of Sealed Soils

Figure 4.9 shows the long-term mean soil water components of an agricultural site in Brandenburg compared to a partly sealed urban area in Berlin. When plants are growing, evapotranspiration consists of interception (an inactive process in which fallen rainwater evaporates directly from the plant surface into the atmosphere), active transpiration by root water uptake of the plants, and evaporation from the bare soil.

If the depth to groundwater is shallow, capillary rise from the groundwater into the root zone can take place and enhance evapotranspiration. The whole soil-vegetation-atmosphere system is driven by two boundary conditions: energy from atmospheric conditions and water supply by rain, soil water, and groundwater to enable evapotranspiration. In the city, evapotranspiration is drastically reduced

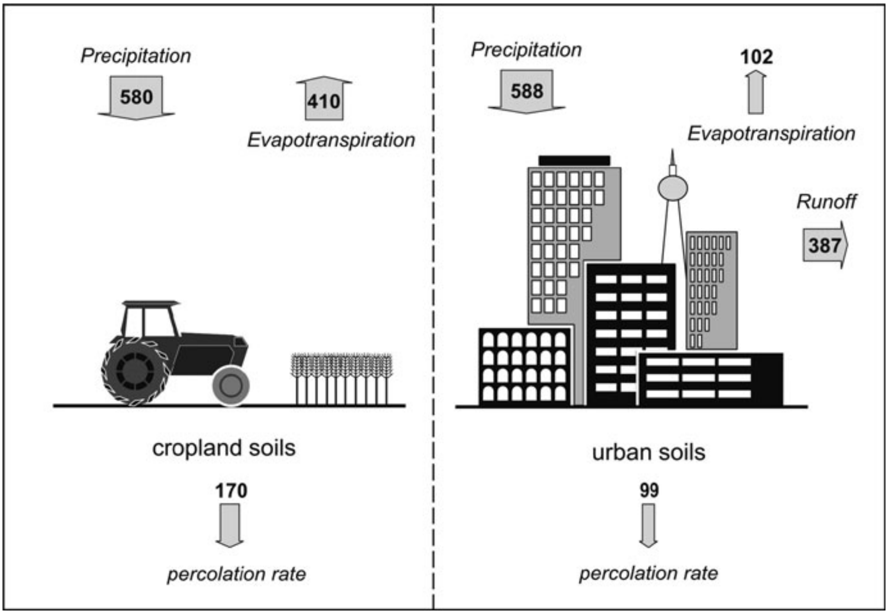

Fig. 4.9 Mean soil water components for arable land in Brandenburg (*left*) and partly sealed areas in Berlin (*right*)

because surfaces are covered by streets, pavements, and buildings. Only small patches of the soil surface are unsealed and participate in the infiltration process. As a consequence of increased surface sealing, runoff also increases and the mean percolation rate is reduced. If the soil surface is sealed, part of the rainfall runs off or evaporates while the rest infiltrates through the soil-filled gaps between the sealing materials. Seam material is often the only infiltration pathway on partly sealed pavement systems. It plays an important role concerning sorption processes of pollutants and for the transport to the upper groundwater aquifer. Partly sealed pavement systems are constructed with retention-weak materials to assure a high hydraulic conductivity (a rapid penetration of water) of the pavement bed and therewith prevent damages of the pavement system, e.g., by frost or flooding.

Different paved surfaces exhibit high infiltration rates (36 up to 180 mm h^{-1}) with a great variability between the different surface coverings as well as between different locations on the same paved area (Illgen et al. 2007). Illgen has shown that the infiltration rates decrease due to compaction and, with increasing age of the seam material, due to clogging effects caused by the accumulation of fine material in the upper layer of the seam material. A decrease in infiltration rates by a factor of 10 or even 100, as compared to newly constructed pavements, was observed for individual sites. Flöter (2006) has found that the infiltration rate on an 8-year-old pavement is still comparatively high. He observed that paving with a seam width of 3 mm and 5% seam material (95% paving stones) infiltrates up to 80% of the rainfall, if the rainfall intensity is low to moderate (<0.5 to 4 mm/h). Only heavy rainfall events cause high runoff rates. In order to derive runoff coefficients with a high resolution Rim et al. (2009) has analysed individual rainfall and runoff events using a weighable lysimeter with different pavement surfaces (Fig. 4.10).

About 160 rainfall events were identified and analyzed from April to September 2009. Rainfall events with intensities of >0.04 mm/min produced runoff from the cobble stone surface, whereas rainfall events with intensities of >0.02 mm/min caused runoff from the concrete slab pavement. After a rainfall event with an intensity of >0.2 mm/min up to 0.5 mm/min, the RCs for the concrete paving surfaces increased at a significantly slower rate compared to their increase at lower intensities. RCs for the cobble stone surface differed in so far, as that they continued to increase even after intensities of >0.4 mm/min were surpassed. These results lead to the conclusion that RCs are subject to a non-linear increase with rainfall intensity until a threshold of about 0.7 mm/min is reached. After that, one can expect the runoff coefficient to remain at a constant value. However, compared to natural soils, surface runoff increases as the infiltration rate decreases. The consequences can be fast and severe for sewage systems or watercourses, a relevant for predicting floods. Furthermore, it can cause an overflow of combined sewage systems, which increases the pollution risk of urban rivers with untreated wastewater (Heinzmann 1998). Another result of the decreased infiltration is a smaller amount of available soil water for evapotranspiration. The processes described above lead to a gain in sensible heat and a loss of latent heat: the city becomes warmer compared to the environment (Wessolek 2008). Soil sealing contributes to the urban heat island effect.

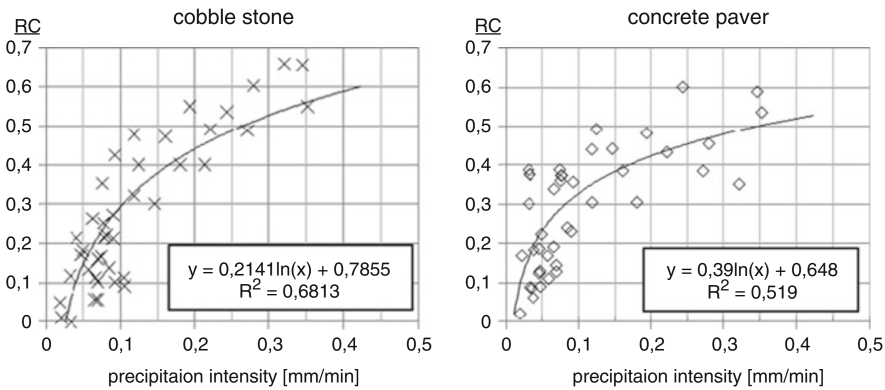

Fig. 4.10 Runoff coefficient (RC) for mosaic cobble stone pavement (*left*) and concrete pavement (*right*) as a function of the precipitation intensity

4.4.3 Seam Material

The term "seam material" describes the soil material developed from technogenic sand used between the pavestones of sidewalks. It has a black or brownish black colour and is mostly only 1 cm thick and contains all kinds of deposited urban dirt and dust, such as leaf litter, hair, oil, dog faeces, food residues, cigarette stubs, plastic packaging, glas shards – in short, any kind of urban waste that is small enough to lodge into the cracks in the pavement after being ground down by pedestrians or vehicles. As a consequence of this unintentional pavement-milling, pedestrians and cars also wear down the soles of their shoes and tyres, sending the resulting abrasions into the seams as well. Figure 4.11 shows a picture of typical seam material in detail.

Over the years, urban dirt and dust accumulates in the upper layer of the coarse sand between the paving stones. This results in a different composition and thus different properties of the upper layer of the seam material (Nehls et al. 2006). Compared to the original sandy seam material, the altered seam material shows significantly higher C_{org} contents and higher amounts of micro- and mesopores, leading to an increase in available water capacity of 0.05–0.11 $m^3\ m^{-3}$. Compared to natural sandy soils with similar contents of soil organic matter, the seam material possesses similar macropore volumes, but, due to the particulate character of its organic matter, the volume of mesopores and micropores is smaller. These characteristics are of particular interest as seam material takes on important soil functions, such as filtering, buffering and groundwater recharge in urban areas with a high degree of sealing, up to >35% (Wessolek 2008).

Among other factors, semi-permeable pavements are also responsible for the infiltration of rainwater in urban locations. The seams allow infiltration and reduce

Fig. 4.11 Photo of dark seam material (0–1 cm) and light original sandy seam filling (1–5 cm) of the sidewalk at Pfluegerstrasse, Berlin

evaporation. As a consequence, groundwater recharge rates are 99–208 mm per annum in sealed areas, compared to only 80 mm per annum for a pine-oak forest around Berlin (Wessolek and Renger 1998). If rainwater accumulates in puddles on the pavement, the groundwater recharge can be greater than 300 mm per annum. Puddles with up to 60 mm depth are no rarity in older neighbourhoods. We gauged a puddle on the pavement in front of our department with a volume of 56 L at a horizontal projection of only 2 m^2.

Rainwater runoff in urban areas is often contaminated, e.g., by heavy metals. Dannecker et al. (1990) and Boller (1997) found Pb concentrations of up to 0.3 mg/L in street runoff, while Cd concentrations were as high as 0.0076 mg/L (Dierkes and Geiger 1999). The high infiltration rates might result in high contaminant fluxes even if dissolved contaminant concentrations are low (Dannecker et al. 1990). An assessment of the risk of soil and groundwater contamination requires sorption parameters for the paving and construction material, which is mainly sand. However, one cannot extrapolate the filtering properties of other soils, because the organic carbon (C_{org}) of this material differs in origin, quality and function from non-urban, natural soils (Nehls et al. 2006). The percentage of black carbon for instance, a "combustion-produced black particulate carbon, having a graphitic microstructure" (Novakov 1984) in C_{org} is higher compared to natural soils. However, the increase of the cation exchange capacity (as an indicator for the sorption capacity) in seam material with increasing soil organic matter content is less distinct compared to agricultural and forest soils as described by Renger (1965) and Wilczynski et al. (1993) respectively (Fig. 4.12). One can conclude that the urban carbon quality (urban dirt or whatever else it may be) is less effective

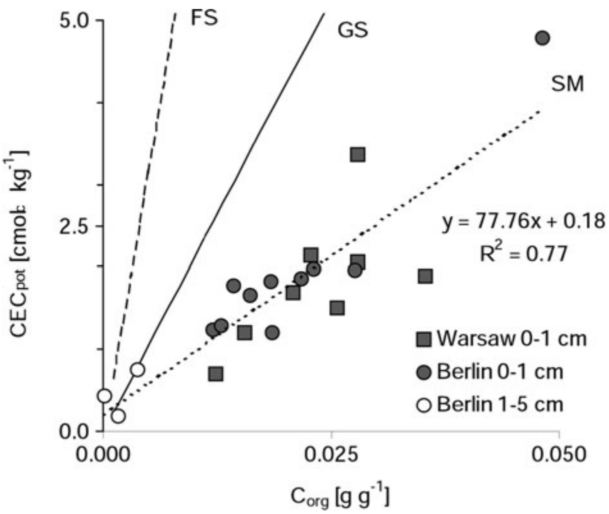

Fig. 4.12 Relationship between organic carbon content and potential cation exchange capacity (CECpot) in seam material (SM), sandy German soils (GS), according to Renger (1965), and sandy forest soils [FS, according to Wilczynski et al. (1993)]

compared to humic substances developed by humification processes in nature. In other words, to reach a sorption capacity of 2.5 cmolc/kg soil only a humus content of 0.6% Corg in a forest soil and 1% Corg in an agricultural soil is needed, but 3% Corg would be necessary to reach this value for an urban soil.

Though the sorption capacity of seam material is less pronounced compared to natural humic substances, seam material is a valuable filter and influences transport processes through the pavement. Nehls et al. (2008) has shown that even after 50 years of heavy metal input by dust and rain, most of the trace elements are still bound in the first few centimetres of the topsoil and not transported into deeper soil layers, despite high water fluxes in the seams.

4.4.4 Weed Control on Pavements

In addition to the important role for the infiltration of water on partly sealed areas, the seam material is also a habitat for plants. Pavements with a high percentage of seam material like mosaic pavements, which are common in Berlin, are especially prone to be partly covered by moss and weeds. However, as the main function of pavements is to provide a stable, secure, dry and level ground for pedestrians, weeds on pavements are often unwanted by municipal departments who maintain city streets and sidewalks. In addition to safety reasons, weed covered sidewalks can also be an aesthetically unwelcome sight in the perception of local residents. The presence of weeds on pavements tends to indicate a city in decline and is thus controlled by the public authorities.

For these reasons different chemical and non-chemical (thermal and mechanical) methods are available and frequently used (Hansen et al. 2004; Kempenaar and Spijker 2004; Rask and Kristoffersen 2007). While non-chemical methods are more time-consuming and therefore more expensive, most public authorities, such as the Berlin public sanitation service (Berliner Stadtreinigungsbetriebe), prefer to use the herbicide glyphosate (mainly in the commercial form of Roundup Ultra) for weed control on pavements as a cost-effective chemical method. In Germany the use of glyphosate on hard surfaces such as pavements and paved driveways, courtyards and squares, is forbidden. An exception for the use of glyphosate on hard surfaces can be granted by the competent authority of the federal states (Bundesländer) in accordance with § 6, 3 of the German Plant Protection Law (PflSchG 1998). Furthermore the authorities can regulate the application technique that should be used. In Berlin the only permitted technique is the application of Roundup Ultra via the risk-reducing roller wiper Rotofix. In contrast to spray applications, this machine coats the weeds with the herbicide via a roller. In this way a direct soil contamination should be avoided. Additionally, the principles of "good professional practice" (BMELV 2005), e.g., no application if rain is likely, are to be observed for every glyphosate application.

While no specific regulations for the use of glyphosate on pavements and road-sides exist in some countries (e.g., Finland, Latvia), other countries, e.g., The

Netherlands and Denmark, have started programs for weed control on hard surfaces aiming to reduce and phase-out herbicide use within urban areas (Kempenaar and Spijker 2004; Kristoffersen et al. 2004). This is ecologically important, as the use of herbicides in urban areas causes different environmental problems compared to their use in agriculture. This is especially due to the minimal opportunity for sorption of herbicides and the small areas of infiltration mentioned above. Water quality monitoring studies have demonstrated that a disproportionate contamination of waters by non-agricultural herbicide use exists (Kristoffersen et al. 2008). Several studies showed that the urban use of the herbicide glyphosate and its degradation products contribute to surface water contaminations (Skark et al. 2004; Kolpin et al. 2006; Byer et al. 2008).

4.4.5 Glyphosate

The herbicide glyphosate is frequently used for chemical weed control in urban areas due to its non-selectivity and its comparatively good environmental properties. Because of its pronounced tendency to adsorb to soil constituents, its fast microbial degradation and its low toxicity, the risk of surface or ground water contamination is generally assumed to be low (Vereecken 2005). Nevertheless, a wide contamination of surface water as well as some groundwater resources with glyphosate and its main degradation product amino-methylphosphonic acid (AMPA) has been reported (Feng and Thompson 1990; Newton et al. 1994). Furthermore, ecotoxicological studies showed negative effects of glyphosate and its formulation Roundup Ultra on non-target organisms in sublethal concentrations (Glusczak et al. 2006; Costa et al. 2008). As glyphosate is the most widely used herbicide in agriculture worldwide numerous studies investigating its fate in agricultural systems exist, especially since genetically modified glyphosate-resistant crops have been introduced in the USA and South America in the last ten years (Scribner et al. 2007). By contrast, investigations regarding the fate of glyphosate and its degradation products in urban areas, e.g., on pavements, are rare (Strange-Hansen et al. 2004; Spanoghe et al. 2005). As above mentioned studies concerning the transport and fate of glyphosate in agricultural systems have shown that the use of this herbicide can be problematic under certain circumstances, it is of great importance to gain more information about its fate in urban systems. Whereas agricultural soils have comparatively high retention capacities for glyphosate, urban systems, such as partly sealed pavements, exhibit low retention capacities and increased runoff and infiltration rates, rendering them more susceptible to negative effects.

4.4.6 Leaching of Glyphosate

Klingelmann (2009) has found unexpectedly high levels of glyphosate and AMPA in the leachate of a lysimeter experiment. She compared a sealed and unsealed

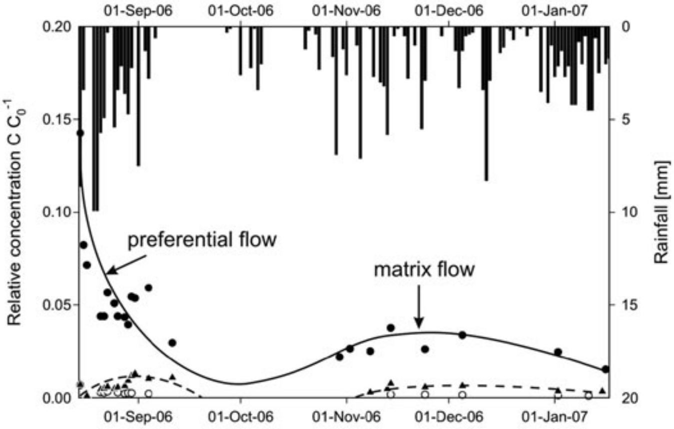

Fig. 4.13 Relative concentrations of glyphosate leaching of an unsealed and partly sealed lysimeter

lysimeter, both of which had been treated with Roundup Ultra from a Rotofix apparatus, just as they are applied in Berlin under site-similar conditions (Fig. 4.13).

The maximum glyphosate concentration in the leachate of the unsealed lysimeter was found to be 81.8 μg L^{-1}, compared to a maximum concentration of 1,184.3 μg L^{-1} of the lysimeter covered with a partly sealed pavement. At the beginning of the experiment a first flush of glyphosate leached through the lysimeter by preferential flow because of high rainfall intensities. Afterwards the herbicide was transported over a longer period by matrix flow. On the paved lysimeter 15.3% of the amount applied was leached in the form of glyphosate and 57.7% was leached as active ingredient equivalent (AMPA). The significantly different amounts of glyphosate and active ingredient equivalent leached from the lysimeters were definitely caused by their different surface covers. The unsealed lysimeter was covered with a 7 cm layer of loamy sand on sandy soil. Its sorption capacity was 14-fold higher than that of the coarse sand of the sealed lysimeter. Due to the higher sorption capacity, the amounts leached via matrix flux from the unsealed lysimeter were much smaller than those from the sealed lysimeter. Nevertheless, the amount of glyphosate transported via preferential flow by the unsealed lysimeter amounted to 0.3% of the total glyphosate applied, and was thus very similar to the amount transported by the sealed lysimeter. This can be explained by similar active pore volumes and the lack of sorption due to the very short contact times with the soil matrix. Even though only 30% flowed through the unsealed lysimeter, the higher pore volume of the unsealed lysimeter yielded the same active pore volume as for the sealed lysimeter. The amount of active ingredient equivalent that was leached from the sealed lysimeter was six times higher than the amount leached from a similar partly sealed lysimeter.

4.4.7 Conclusions

In urban areas sealing of soil surfaces often leads to ecological problems caused by the increased and accelerated runoff and reduced evapotranspiration in comparison to non-sealed soils. Therefore, cities are normally drier and hotter than the surrounding areas. During heavy rainfalls the excess water causes mixed sewage systems to overflow. This is one of the main threats to water quality of urban water bodies. Therefore, runoff reduction by increasing infiltration is one of the main ideas of ecological urban planning. This goal can be reached by an increased use of pervious pavements with a high degree of seam material. In many European cities, especially older ones, pervious pavements are common and used to infiltrate the rainwater directly in order to prevent runoff. We should encourage the practice of such traditional city planning ideas by avoiding a complete surface sealing and by keeping the soil water in the local system as long as possible. The natural infiltration processes of urban soils and seam material also cleans the percolation water and plays an important role in protecting groundwater. Moreover we can come to appreciate that even urban dirt has a filtering and buffering function. In a certain way one can say that dirt cleans dirt.

Finally a few comments should be made about the use of chemicals in weed control on urban pavements. Even though the experimental conditions enhanced natural percolation rates by preventing the occurrence of runoff and restricting the leaching depth, the glyphosate results suggest that the use of glyphosate in urban areas should be fundamentally challenged and further experiments concerning the leaching and runoff of glyphosate in urban areas should be conducted. If the use of glyphosate is deemed necessary, it should be limited to exceptional cases, in consideration of the following points. Due to the measured background concentrations of AMPA, the application of glyphosate should be limited to once a year.

The coarse sand and gravel normally used for pavement construction are likely to have low sorption capacities for glyphosate. Therefore, the application of glyphosate on partly sealed urban areas should be differentiated according to the construction age of the partly sealed areas, the geological parent material and the percentage of seam material, as leaching volumes from areas with a low percentage of seam material, like the lysimeter with 5% seam material, seem to be higher.

Klingelmann's study (2009) was limited to the leaching of glyphosate through soil on partly sealed areas. However, the transport of glyphosate with runoff is a hydrological bypass due to the missing retention in soils. In this case, contaminated water is routed directly into sewage systems or surface waters. This might be the more crucial issue regarding the contamination of surface waters with glyphosate. As methods for non-chemical weed control (mechanical and thermal methods) and combinations of chemical and non-chemical methods have been well tested (Hansen et al. 2004; Kempenaar and Spijker 2004; Kempenaar et al. 2004; Rask and Kristoffersen 2007), chemical application methods in urban areas should be substituted and reduced as much as possible.

4.5 Roadside Soils

The construction, traffic and maintenance of major roads and motorways significantly change the original physical, biological and chemical properties of the soil directly on-site and in the surrounding area. Figure 4.14 shows a schematic cross section of a road and the influenced road environment.

Under the asphalt and/or concrete layers of the road surface there is generally a gravel layer with high (=proctor) density for stabilization and frost protection. This gravel layer is typical for Central Europe, whereas in countries without frost seasons such a layer is not necessary.

During road construction, the organic topsoil was either taken away or left buried beneath the gravel layer in depths of >1 m. The hard shoulder, built in the course of the road construction, measures about 1.5–5 m and is located directly along the asphalt edge. This part of the road is necessary to infiltrate the street runoff and consists of gravel-sand mixtures with high-saturated hydraulic conductivities. The 5–8 m of soil adjacent to the hard shoulder are mostly compacted and disturbed with little to no vegetation. After this distance the influence of the road slowly decreases and after 10–15 m predominantly original soil profiles are to be found.

Roadside soils often contain up to 30% technogenic materials and stones. These are calcareous (2–10%) and have a pH value of >7.0. Due to traffic emissions, trace elements at the soil surface (0–30 cm) greatly increase up to a distance of 20 m.

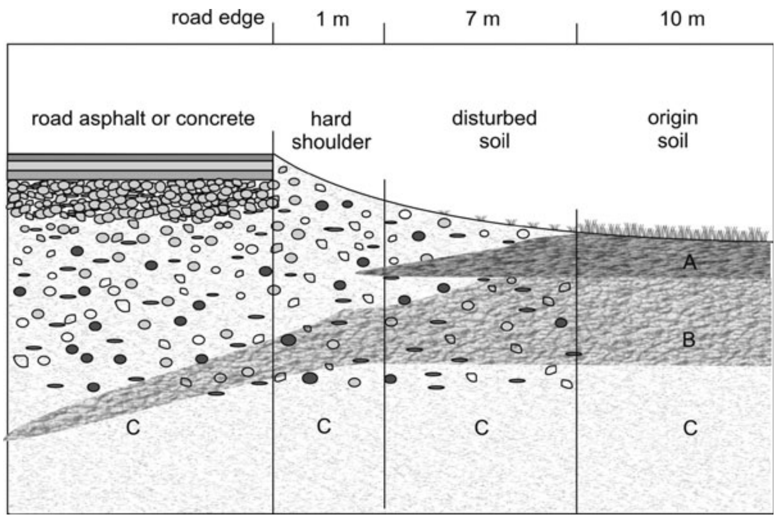

Fig. 4.14 Schematic cross section of a roadside soil

4.5.1 Sources of Pollution from Roads and Vehicles

The pollutants of the roadside environment originate from a variety of different sources, including:

– Automobile exhaust emissions
– Automobile component wear
– Road degradation
– Atmospheric deposition
– Discarded waste (litter)

Emissions from automobiles not only stem from the residues of complete fuel combustion (CO_2 and H_2O), but also from the residues of incomplete fuel combustion, oil leaking from engine and hydraulic systems, fuel contamination, fuel allowances, and wear of engine parts. A high potential source of pollutants is also the abrasion of the road surface itself, as well as the corrosion and wear of individual vehicular components such as the car body, tires, brakes, clutch or motor parts. A quantification of the release of individual building components is difficult because the composition varies widely depending on the manufacturer. Nevertheless, some studies have been carried out on the release and deposition rates of particulate pollutants from motor components and road degradation (e.g., Revitt et al. 1990; Muschak 1990).

Thus, a very complex mixture of pollutants is emitted in the area of the roadside soils. These are mainly:

– Carbon monoxide
– NOx
– Hydrocarbon (HC)
– Sulphur dioxide
– Methane (CH4)
– Lead, copper, zinc, cadmium, nickel, chromium and other heavy metals
– Organic pollutants such as PAHs.

4.5.2 Mechanisms of Dispersion

Most pollutants are emitted in a gaseous state or are deposited on the road as fine particles. Figure 4.15 shows a typical view of a road with pathways of dispersion by dry and wet depositions into the roadside environment.

The pollutants are transported across the road surface with the rain and then deposited as suspended or dissolved particles. Depending on the type of road and the inclination of the hard shoulder, spray and road runoff water can be transported as far as 10 m across the adjacent roadside area (Golwer 1991; Kocher 2007). With the additional influence of wind and airflow, very fine particulate matter can be transported up to a distance of about 25 m and deposited in the surrounding area

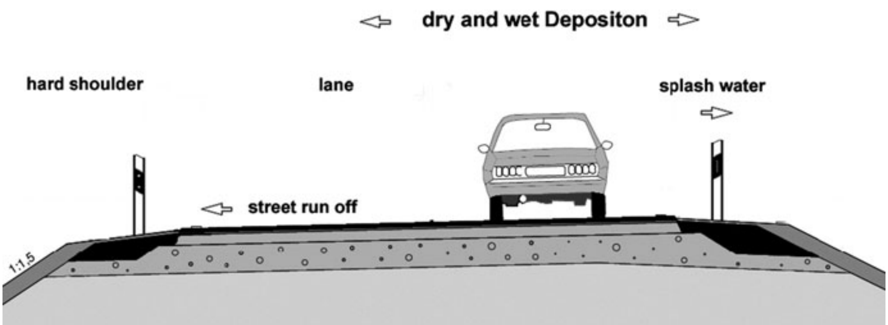

Fig. 4.15 Road with the pathways of dry and wet deposition

(Boller 2006). An analysis of studies on major roads and motorways (Golwer 1991) determined three different areas of pollution for roadside environments. These are:

– The range of 0–2 m, which is dominated by runoff water from the road and splash water
– The range of 0–10 m, which is partly influenced by splash water and partly by runoff water, depending on the inclination of the hard shoulder
– The range of 0–100 m, affected by airflow and wind

Dry depositions under the influence of traffic have shown higher concentrations of heavy metals and many organic contaminants, than comparable counterparts in rural environments. Wet depositions of urban areas, in the form of street runoff and also spray water, contain high concentrations of pollutants, in comparison to normal precipitation (Harrison et al. 1985; Makepeace et al. 1995; Wigington et al. 1986).

The composition and amount of dry and wet deposition depends on many factors, such as the particle size of the pollutant, traffic intensity, wind direction, wind velocity, rain events and intensity, previous dry periods, vegetation cover or construction of urban canyons and motorway design (Barbosa and Hvitved-Jacobsen 1999; Pagotto et al. 2001). In urban areas the construction and road design are important factors that influence the amount and the dispersion of soil pollution.

An example of the amounts of dry and wet depositions is given in Fig. 4.16. The study site is located on the motorway A7, north of the city of Hannover. The average daily traffic (ADT) is about 75000. The input of heavy metals is highest in the first few meters from the road's edge, and the decrease of depositions with distance is clearly visible. After 15 m the depositions return to the range of the background levels, even though after 100 m slightly increased heavy metal concentrations were measured in the upper centimeters of the soils (Kocher 2007).

4.5.3 Wet Depositions: Run Off

The composition of wet depositions is influenced by a variety of factors, including traffic, road catchment area, rainfall frequency and intensity, antecedent moisture

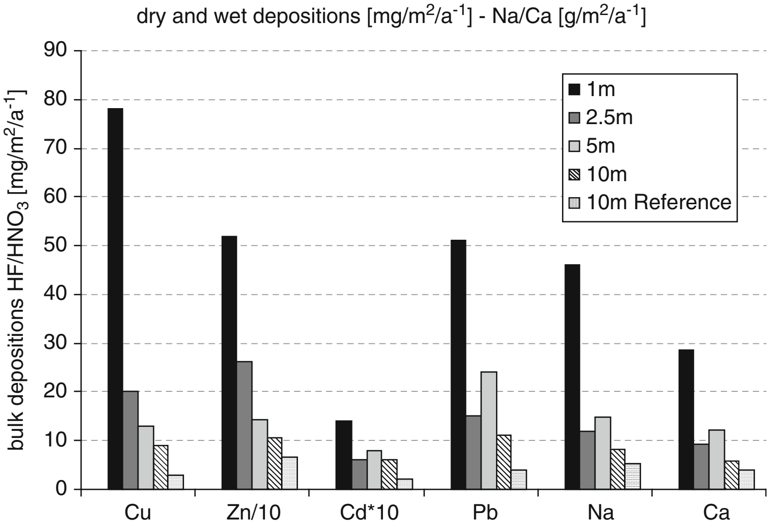

Fig. 4.16 Total depositions of Cd, Cu, Zn, Pb, Na and Ca at different distances from the roadside (A7, ADT 75000)

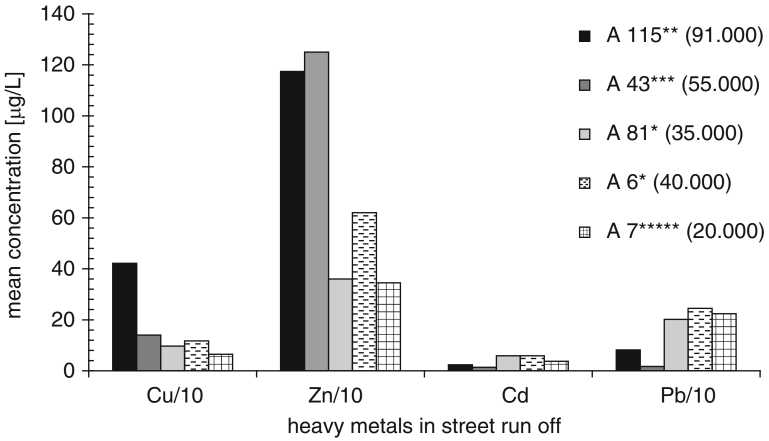

Fig. 4.17 Average concentrations of heavy metals in road runoff from different motorways in Germany (**Kluge 2010; ***Dierkes and Geiger 1999; * Muschak 1990; *****Diehl 2002)

conditions, road surface conditions and wind direction (Barbosa and Hvitved-Jacobsen 1999; Sansalone and Buchberger 1997; Polmit 2002; Kocher 2007; Göbel et al. 2007). However, a comparison of average pollutant concentrations in runoff of different motorways in Germany shows a similar range for the concentrations of Cu, Zn and Cd (in relation to vehicles) despite different sampling intervals and rain events (Fig. 4.17).

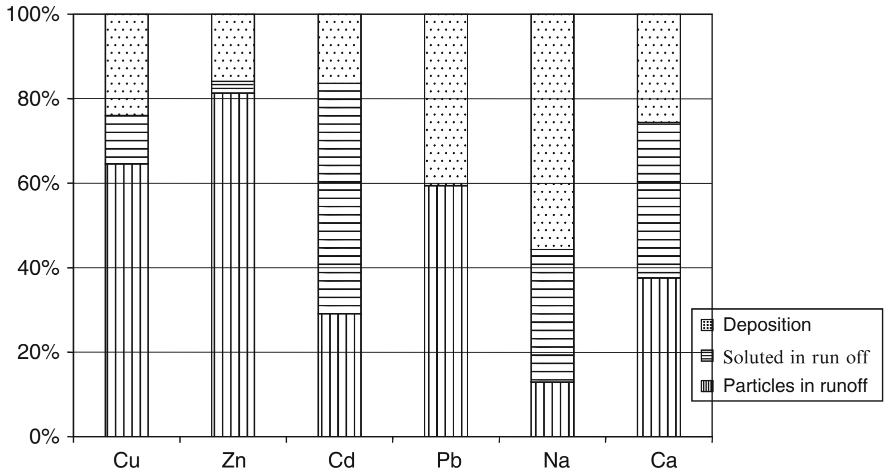

Fig. 4.18 Fractions of heavy metals of total depositions of a motorway (0–1 m distance, A7 – Hannover)

Figure 4.18 shows an example of the distribution of the deposited substances divided into dry and wet depositions (dissolved and particulate). Large fractions of Cd, Na and Ca were transported in a dissolved state, whereas Pb and Zn were mostly transported by airflow and solid fractions of road runoff.

4.5.4 Heavy Metal Concentrations in Roadside Soils

It is well documented that heavy metal contents in roadside soils decrease with distance to the road and with soil depth (e.g., Motto et al. 1970; Harrison et al. 1985; Turer and Maynard 2003; Li 2006). Figure 4.18 shows an example of heavy metal concentrations in roadside soils (0–10 cm) at the AVUS motorway. The AVUS motorway is located in the southwest of the capital Berlin. It was inaugurated in 1921 and is considered to be the oldest motorway in Europe; the ADT is about 100,000 vehicles with a high percentage of lorries.

In comparison to the mean natural, i.e., geological, background levels for the region of Berlin/Brandenburg, the concentrations of all heavy metals at the soil surface (0–10 cm) are greatly increased right up to the investigated distance of 10 m (Fig. 4.19). Zinc was the heavy metal with the highest levels in the soil, ranging from 8 to 804 mg/kg. Mean concentration at 2.5 m was 172 mg/kg, which is approximately ten times higher than the background level. Copper concentrations ranged from 2.9 to 565 mg/kg. The mean concentration at 2.5 m was 55 mg/kg. This value is about five times higher than the mean background concentration. Concentrations of lead ranged from 10.6 to 426 mg/kg. Mean concentration at 2.5 m was 177 mg/kg, which is eight times higher than the background level. Cadmium concentrations varied from 0.1 to 4.3 mg/kg. The mean concentration at 2.5 m

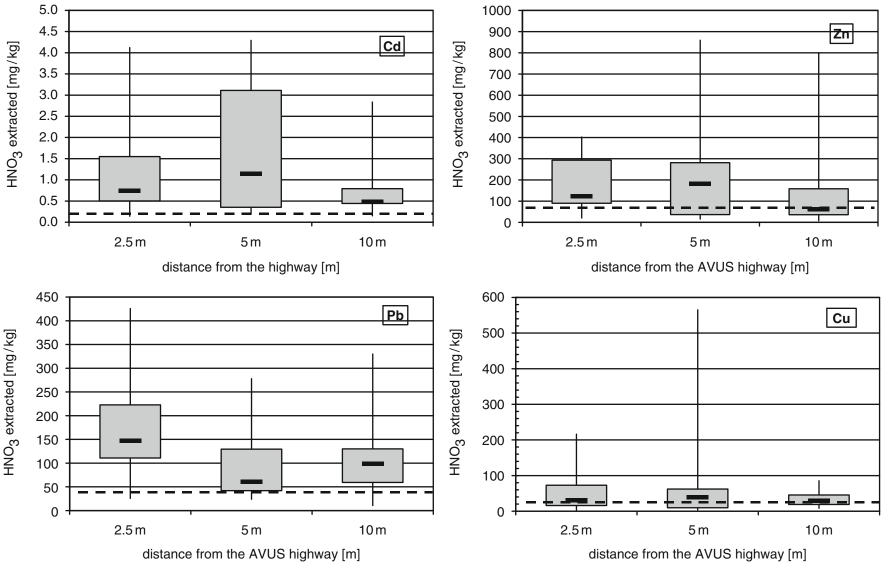

Fig. 4.19 Median concentrations Cd, Zn, Pb and Cu in the roadside soils at different distances from the roadside edge at the AVUS Highway, Berlin; soil depth = 0–10 cm; HNO3 extracted; $n = 60$ (Kluge 2010)

was 1.1 mg/kg, which is seven to eight times higher than the mean background value. At most sampling points this meant that concentration rates for all investigated heavy metals exceeded the precautionary values of the German Federal Soil Protection and Contamination Ordinance (BBodSchV) as much as tenfold.

4.5.5 Water Balance

The water balance of the road embankment, located directly next to the road (0–2 m), is mainly influenced by the road runoff water (Fig. 4.20). The annual infiltration rates at the roadsides of major streets or motorways that are drained over the hard shoulder are up to five times higher than the annual infiltration rates of sites not influenced by street runoff.

Measurements of the infiltration depth of percolation water at a motorway site in northern Germany (AVUS – A115, Berlin – precipitation 550 mm per annum) show that infiltrating water could reach soil depths of up to 12 m within 1 year. In the area that is influenced solely by spray water (up to 5 m), the depth decreased to 1–2 m. At a distance of >5 m from the roadside the annual infiltration of soil water is only influenced by rainfall and reaches depths of about 1 m (Kocher 2007).

Taking the runoff and splash effects into account, one can calculate the average percolation rate for the three parts of the road system: asphalt, hard shoulder and splash area. Note that evapotranspiration is drastically reduced compared to natural

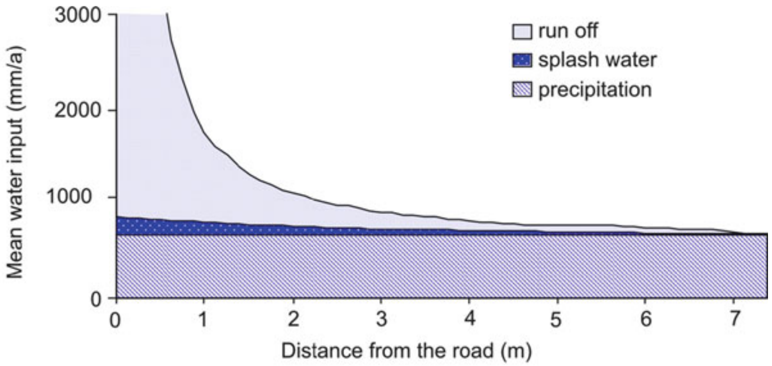

Fig. 4.20 Mean annual water input in roadside soils of runoff, splash water, and precipitation for various distances from the road

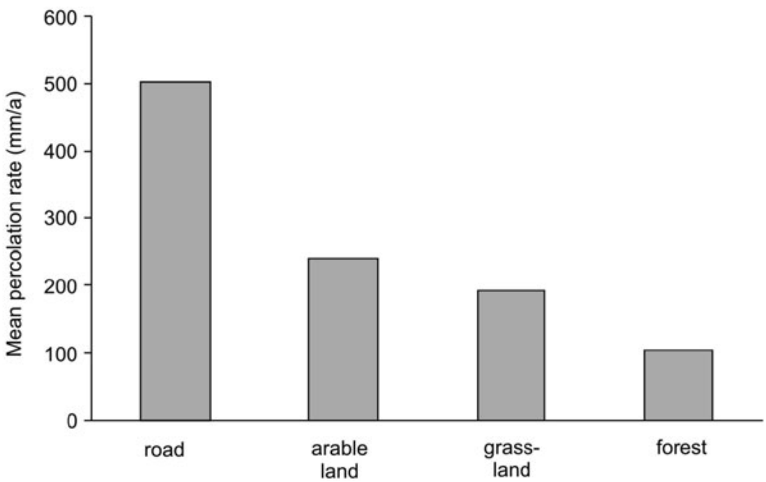

Fig. 4.21 Mean annual percolation rate in northeast Germany for different land use systems: roadside soils, arable land, grassland, forest

conditions because plants only grow sparsely beside the road. Figure 4.21 compares the mean annual percolation rates of a motorway with arable land, grassland and forest for the region of Hannover in the lower Saxony of Germany. Roads are lines with percolation rates more than twice as high as the rates of arable land and up to five times as high as the rates under forests.

4.5.6 Leaching of Trace Elements in the Vadose Zone: Cadmium

Figure 4.22 shows an example of the leaching of cadmium in the vadose zone beside a motorway as a function of the distance from the roadside. The annual

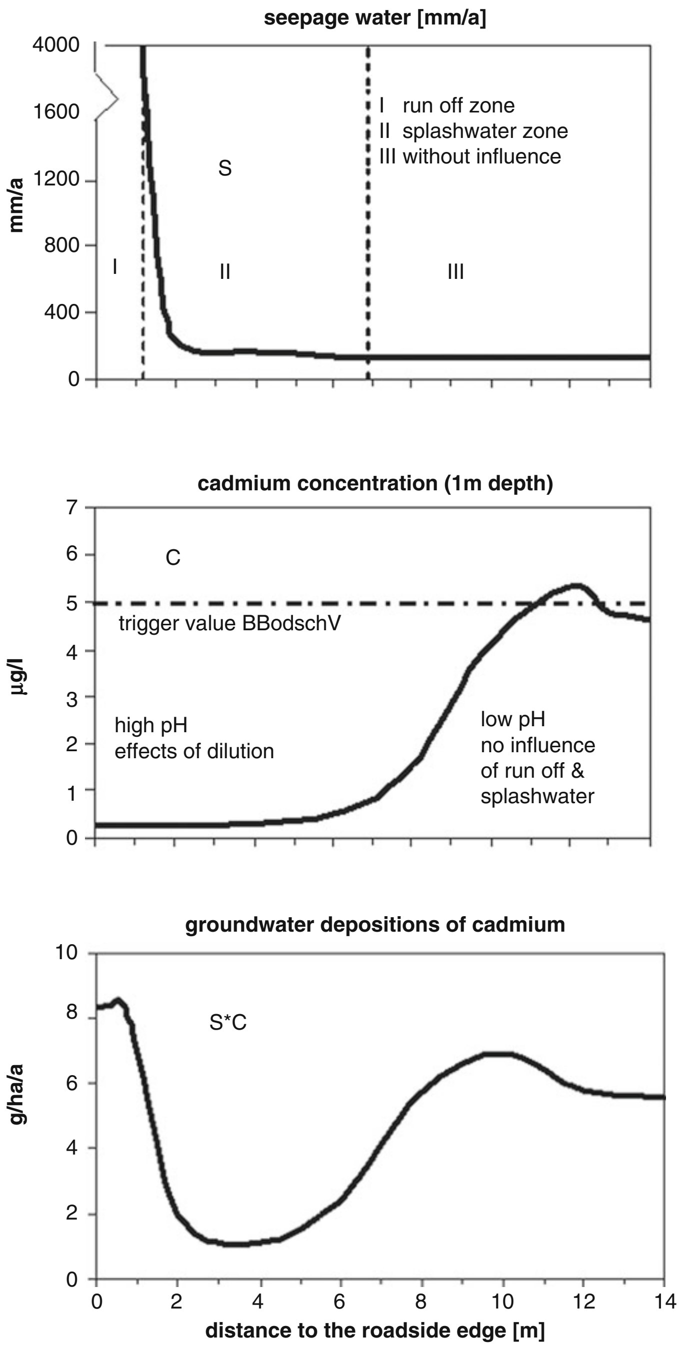

Fig. 4.22 Mean annual percolation rate (*top*), mean cadmium concentration in soil solution at 1 m depth (*middle*), and leaching rates (*bottom*) for various distances from the road

leaching rates (Fig. 4.22, bottom) were estimated by using the mean annual percolation rates (Fig. 4.22, top) multiplied with the average Cd concentration of the soil solution at 1 m depth (Fig. 4.22, middle). Due to high pH values and high infiltration rates in the first two metres beside the road only low concentrations of cadmium are to be found. Nevertheless, the high infiltration rates lead to high leaching rates. In contrast, a low pH value induces high solute concentrations at distances >8 m from the road. However, the percolation rates at these distances are low and not influenced by runoff and splash water any more. Thus the leaching rate is quite similar to the one of the hard shoulder of the road (BbodSchG 1998).

4.5.7 Leaching Scenario of Cd in the Vadose Zone over the Next 100 Years

Though most trace elements in roadside soils are relatively immobile, long-term leaching behavior is difficult to estimate. In order to predict solute and solid concentrations for long-term periods, numerical simulation models such as HYDRUS can be employed. For its use one needs trace element sorption/desorption characteristics of the roadside soils as well as information about the dry and wet emissions, such as the results shown in Fig. 4.16.

Figure 4.23 exemplifies desorption characteristics for Cd for two roadside soils with different pH (pH 6 and pH 4) values. At low solid concentrations of up to 3.5 mg Cd/kg, similar solute concentrations occur. However, at high Cd concentrations in

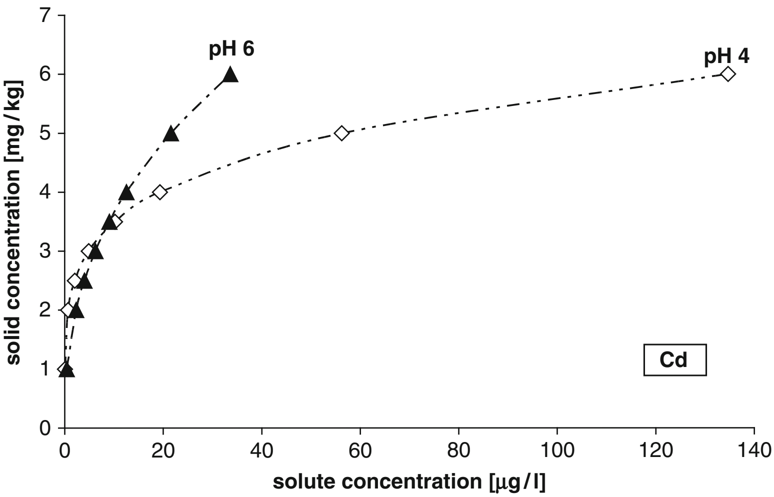

Fig. 4.23 Cadmium desorption characteristics of two roadside soils, one with pH 4 and the other with pH 6 (Kluge 2010)

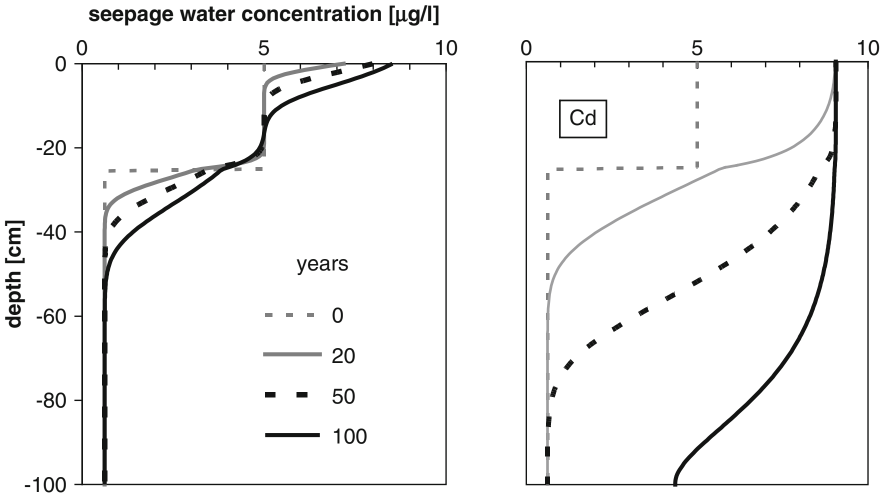

Fig. 4.24 Predicted Cd solute concentrations for two different motorway soils. The *left* part shows the solute depth concentrations at a distance of 10 m from the Avus motorway, the *right* part demonstrates a similar prediction, but for a recently constructed motorway with a low pH of 4.0 (Kluge 2010)

the soil matrix, the solute concentration of the soil with a low pH is increased greatly because of the decrease in sorption behavior.

Finally, Fig. 4.24 gives an example of long-term behavior of the heavy metal solute concentration for two different motorway soils. The left part of the Fig. 4.24 shows the predicted Cadmium solute depth concentrations at a distance of 10 m from the Avus motorway. The pH value of this soil is high because of high carbonate input from the long-term abrasion and weathering of the motorway surface. By contrast, the right part of Fig. 4.24 shows a scenario of a new motorway with low pH of 4.0, which is typical for the pedo-geological situation in northeast Germany. One can see the expected solute concentrations of up to a depth of 1 m for four time spans: at the beginning (0 years), after 20, 50 and 100 years. High values for the Cd solute concentration of the Avus are only to be found in the first centimeters for all time spans. In depths of >50 cm the concentrations are low because of the high sorption capacity of the topsoil. By contrast, we expect high Cd solute concentrations in the soils near the new motorway for the next 50 years, due to continuous traffic emissions and low sorption capacity of the topsoil at the beginning.

4.5.8 Conclusions

Roadside soils are strongly influenced by construction features and traffic emissions. Both result in disturbed and compacted soils with high concentrations of trace elements in the topsoil. The trace element concentration of the soil solution in the main infiltration zone of the hard shoulder is low because of high dilution. However, in these areas, high leaching rates might occur.

Though the input of heavy metals dates back to more than 100 years for some motorways, no study has observed a significant transport of trace elements deeper than 60 cm soil depth. Even for preferential flow conditions, particle transport is mostly limited by the depths of the transport fingers and cracks. We therefore conclude a low risk of groundwater pollution for the next 100 years. Potentially hazardous situations may arise for the soils of recently constructed motorways with low pH and low sorption capacity. As tested in a field and laboratory study by Kluge (2010), this potential risk was shown to be reduced by adding lime, clay or humic substances to the topsoil after construction work was completed. Potentially hazardous situations may arise for the soils of recently constructed motorways with low pH and low sorption capacity. This potential risk could be reduced by adding lime, clay or humic substances to the topsoil after finishing the construction work as it was tested in a field and laboratory study by Kluge 2010.

4.6 Visualizing the Vadose Zone

4.6.1 From Education to Creative Communication

Who bothers to look down at the sidewalk? More importantly, how can we successfully direct attention towards it, and to the significant role of soils in the city? In recent years knowledge transfer of soil scientific research to people without backgrounds in environmental studies has become increasingly important. In "The Future of Soil Science", edited by Alfred Hartemink for the International Union of Soil Science in 2006, 55 top researchers from 28 countries highlighted issues such as soil degradation, food security, soil management issues, as well as traditional concerns such as soil classification and soil mapping. Fourty-nine out of the 55 authors also listed communication of soil issues as a top priority. The central idea is that better communication may not only lead to change in perception and behavior, but also to better resource management, and ideally a culture of conservation.

"Extending information about soils," writes soil-communicator, Rebecca Lines-Kelly and Jenkins (2006), "is about making the invisible visible, helping people look beyond dusty, familiar surfaces into secret, hidden depths." Lines-Kelly has authored numerous publications and educational materials, writes a regular "soil sense" newspaper column, and has organized workshops for Australia's NSW Department of Primary Industries. Other publications have encouraged stronger integration of soil science in education from kindergarten through university (Herrmann 2006; Smiles et al. 2000), better public reference tools (Van Baren et al. 1998), consideration of social scientific research (Greenland 1991; Minami 2009; Winiwarter 2006) and the role of creative disciplines such as art, film, theatre and music in celebrating the beauty and cultural meaning of soil (Feller et al. 2010; Van Breemen 2010; Toland and Wessolek 2010). Furthermore, programs such as the German Soil Science Society's "Soil of the Year" campaign and museums such as the Underworld Exhibition in Osnabrück (Unterwelten Ausstellung des Natur und Umweltmuseums am Schölerberg) play a vital role in bringing soil knowledge above ground and into public view. Other educational exhibits include the ISRIC World Soil Museum in Wageningen, NL, the Underground Adventure at the Field Museum of Chicago, the Dig It! The Secrets of the Soil exhibition at the Smithsonian National Museum of Natural History in Washington D.C., and the Dokuchaev Central Soil Museum in St. Petersburg, Russia.

Museums and educational programs represent one type of environmental communication. These are, however, often gauged at particular target audiences (mostly school children) and do not usually incite or critically engage in cultural debate. According to some authors, such programs may not even foster lasting interest in youngsters. In his review article on soil education developments in Germany, Ludger Herrmann (2006) mentions a study of high school students interviewed in Osnabrück, Germany's "city of soils." Despite exposure to soil educational programs since childhood, not one interviewee chose to pursue a career or university degree in soil science (Anlauf and Rück 2005).

While education and public outreach programs initiated by scientific institutions are still crucial for the sensitization of future generations, a more intuitive cultural discourse can be observed in the arts and humanities, especially in cities where cultural enterprises thrive. It is to the creative disciplines that soil science might turn to find new allies in communication. And it is through cross-disciplinary collaboration between the arts and sciences that socially significant knowledge transfer and dissemination may take place. In the following, we outline our current investigation of the communicative potential of art as it addresses concerns discussed in other parts of this chapter: soil sealing, storm water run-off and rubble soils.

4.6.2 Storm Water Retention as Sculpture

A functioning vadose zone begins with ecosystems-oriented urban planning. This ranges from re-interpreting zoning laws, to on-site storm-water retention, site-specific water treatment and wetland mitigation. In city centers, where open space is usually scarce and contamination from run-off is higher, small-scale water-retention solutions include green roofs and facades, onsite infiltration strips around buildings and along roads, and the use of water-retention friendly materials. As these solutions are design opportunities as well as engineering tasks, they must be aesthetically pleasing as well as functional to gain acceptance. In recent years, a number of artists have taken on the vadose zone as subject and setting of their work, either by participating in wetland mitigation schemes, creating works that bring attention to threatened ground and surface water, or by creating custom works for newly created treatment wetlands. In this way, permeable pavements, bio-swales, berms and basins are used as formal sculptural media to bring attention to urban soils.

In the early eighties Gary Riveschl, for example, demonstrated in his "break out" installation (Fig. 4.25) the necessity for opening pavements in order to give nature and rainwater more space. At that time political proponents of the green parties started to demand the renaturalization of hydrologic systems in cities. Over the last 20 years it has become state of the art to design rainwater infiltration solutions for inner-city locations in order to close the hydrologic cycles. One such state of the art solution is the use of permeable pavements in non-risk green and residential spaces. In the ongoing work, Waterwash™ (Fig. 4.26), artist Lillian Ball has been working to rejuvenate degraded wetland sites in Mattituck, Long Island, and the Bronx by using Filterpave™ permeable pavements and native wetland plants. Integrating benches and interpretive signage, Ball's work is educational, recreational and functional as it is aesthetic. With a grant form the National Fish and Wildlife Foundation's Long Island Sound Futures Fund and construction and maintenance support form the Group for the East End, Ball's goal as an artist is simply "to get green infrastructure out in the world" (Ball, in an email from 2009). Waterwash™,

Fig. 4.25 Gary Rieveschl, *Breakout*, Gütersloh, 1980

Fig. 4.26 Lillian Ball, *Waterwash*™, Mattituck Inlet Park, 2007–2009

Ball writes, is "…proof that multiple challenges can be solved with integrated functional aesthetics, improving the area both physically and environmentally…"

In another storm water retention project, artist Jackie Brookner created two sculptural works for the Roosevelt Community Center in downtown San Jose, CA. The project, *Urban Rain*, consists of two sculptures that collect and treat storm water from the roof of the LEEDs certified building. The *Coyote Creek Filter* adorns the south entrance of the building, using slate, stainless steel and amber glass to frame a filter that can process runoff from an area >2,300 m^2. A map of the Coyote Creek watershed is etched on to the face of the filter, which sits in a larger filter containing rocks and reeds. On the northern side of the building, stainless steel chutes gracefully direct storm water from the roof onto a giant stainless steel thumbprint that gently presses down on the surface of the soil. The water is filtered through 60 cm deep bed of rocks before flowing into a series of bio-swales, which curve around the side of the building. The Thumbprint Filter can process water from about 1,700 m^2 roof for a storm event of 1.3 mm/min (Figs. 4.27–4.29).

Melody Tovar (2009), deputy director of Watershed Protection for the City of San Jose Environmental Services, describes the environmental and communicative benefits of Brookner's work: "First, the stormwater system, integrated into the artwork, will reduce the volume an improve the quality of the water… Second, by providing demonstrations and monitoring, the artwork will expose and encourage these approaches to our community of developers and residents." In the words

Fig. 4.27 Jackie Brookner, *Urban Rain*, Roosevelt Community Center, San Jose, 2008

Fig. 4.28 Amy Franceschini and Future Farmers, *Victory Gardens*, San Francisco City Hall, 2008

Fig. 4.29 A. Toland and G. Wessolek, Spatial analysis of WWII rubble deposition in Berlin, under consideration of sulphate leaching, recreational quality and collective memory, Altes Museum Berlin-Neukölln, 2010

of the artist, however, an underlying conceptual layer provides the magic that differentiates *Urban Rain* from landscape architecture or hydrological engineering: "Whenever in this city we see rain, we see ourselves..." (Brookner 2009). Through the symbolic gesture of using a human thumbprint as the interface to the pedo-hydrological cycle, a personal relationship to the vadose zone is created in Brookner's water treatment sculpture.

4.6.3 Gaps in Knowledge Transfer

If soil science is the leading force in the pursuit or production of soil knowledge, visual art and its sister disciplines, design and the performing arts can be seen as articulating a *form* of soil knowledge (see also Kurt 2003). This in turn can generate interest, inspiration and action in a wider public. What do artists know about the soil? What could the artistic *form* of soil knowledge look like? With what creative gestures could a culture of conservation be visualized?

To address these questions, we carried out 15 in-depth interviews with artists who have worked with soil or soil conservation issues in urban and industrial areas (Toland 2010, in forthcoming). Artistic formats of the interviewees included sculpture, installation, illustration, painting, performance, video, participatory interventions, and landscape design. Environmental themes included moor degradation, acid mine drainage, rainwater harvesting, urban agriculture, pedodiversity, and coastal reforestation. Given this wide range of concerns and artistic approaches, the topic of didactic aesthetics was addressed in all of the interviews. Did these artists share a common goal of communicating or educating their audience? Although most of the artists answered that they thought about content first and then form, about half of the artists felt that art should inspire through innovative form, rather rely too heavily on informative texts or educational props. All artists described the importance of research in their work. Some had built up their own areas of expertise while others depended more on the expert input of others. All but one artist described instances of collaboration, which differed when working with other artists, scientists, city planners and educators. All artists described an interdisciplinary nature to their work and expressed interest in collaborating with scientists and engineers, if they had not already done so.

A second aspect that came up in the interviews points towards a highly personalized context of environmental protection. One artist described her art as a form of subservience – a service to community and environment. Other artists described their work as a moral, ethical or spiritual duty to nature. The point here is that art can and perhaps *should* communicate much more than facts or findings from scientific studies. To truly create awareness, art needs to address not only modes of aesthetic perception, but also bigger questions such as the human handling of soil, and the individual, cultural and political relationships with the earth. Such issues are often missing in the current paradigm of soil protection, and are generally taboo in scientific research.

Thus, if there is one thing that art is equipped to communicate, it is passion. While traditional soil communication tools can be used to inform city people about the history and science of soils, art may help people to identify with urban dirt as if their backyards and streetscapes were fertile valleys. It is in this sense that guerrilla gardening is becoming a new art form in cities worldwide. Projects such as Future Farmer's Victory Gardens on the lawns of San Fransisco's City Hall (Franceschini 2008); Haeg et al. (2008) "attack on the front lawn" and Nomadic Green's Prinzessinnengarten in downtown Berlin have attracted the attention of urbanites from all walks of life, turning food production into a cultural spectacle and community event.

Despite this recent boom in urban food production as creative public action, not much is known about the extent of knowledge these avantgardeners have about filtering and buffering functions, the dangers of glyphosate or the hydrological behaviors within the vadose zone. For farming, forestry or mitigation to function as sculptural or performative art, lasting partnerships with scientific bodies are necessary. Of the several artists interviewed who had either participated in or initiated community gardening projects, intensive time and work had been invested in experiences that didn't always yield fruit. To assist artists working with food production systems, long-term reclamation of degraded environments and social environmental justice, more research and practical guidelines are needed on knowledge transfer practices between soil science and the arts.

Bouma and Hartemink (2002) have emphasized the need for interdisciplinary research programs to support communication between soil scientists, planers, politicians, and other stakeholders. The cultivation of professional research partnerships is also necessary for accurate knowledge transfer between scientific and artistic disciplines. Organizations such as the Leonardo International Society for the Arts, Sciences and Technology (ISAST), and the Art and Science Collaborations Inc. (ASCI) attempt to bridge this divide. International environmental protection and communication projects such as Cape Farewell and the 350.org campaign have also brought together artists and scientists to raise awareness about climate change. Despite isolated examples, no equivalent interdisciplinary program yet exists to address soil conservation issues on a larger cultural scale.

4.6.4 Science Meets Art

The Department of Soil Protection at the TU-Berlin has been investigating several approaches to pedo-aesthetics in recent years. Projects have included: a soil and art group that was founded in 2000, the organization of several soil-art exhibitions, and a permanent collection of soil-art on display in the University. In 2007 and 2008, we led a series of creative field exercises in an overgrown urban lot near the TU campus. Landscape planning and environmental engineering students and staff were encouraged to paint their impressions of the site with materials found on or buried in the soil. Since 2002, several thesis papers and three student projects have also dealt with the topic of soil and art. For example, Andreas Vetter created plans for an urban soil park, including a sunken soil-auditorium for listening to the earth. Hardy Buhl installed a giant "soil cake" sculpture to demonstrate the remediation of a former wastewater-leaching field. In another example, Fritz Kleinschroth and the project group Soil Art on Urban Brownfields created an "ecological foodprint" in the shape of an oversized foot made out of kitchen scraps from a homeless shelter. A time-lapse video of the event illustrated processes of humification and mineralization. More student films can be found on youtube under: media, soil, tu-berlin.

In a latest effort, we participated in a three-week interdisciplinary workshop, "Science meets Art," initiated by Ping Qui for the Swiss Foundation for the Arts, Pro Helvetia. Eight artists met regularly with eight scientists and engineers to discuss research interests, methods, and the overarching cultural roles of science and art. Although points of contention came up in discussions on the funding and cultural contexts that define certain activities as "scientific" and others as "artistic," many parallels were also emphasized. Both are solution oriented. Both operate with a sense of a devotion and commitment to their work. Wilson (2002, p. 18) has highlighted other similarities of contemporary artistic and scientific practice: "Both value the careful observation of their environments to gather information through the senses. Both value creativity. Both propose to introduce change, innovation, or improvement over what exists. Both use abstract models to understand the world. Both aspire to create works that have universal relevance."

In an impromptu charrette, the group was given 1 week to create a formal interpretation of the previous weeks interactions in the former city museum of Berlin-Neukölln (Heimatmuseum Neukölln). We based our work on the ongoing research on WWII rubble. In a room with a low ceiling we sketched a map of Berlin on the floor and covered it with rubble, leaving only the waterways exposed. We placed 1 m-tall Plexiglas columns filled with rubble on the 13 points of greatest rubble deposition (such as Teufelsberg and Humboldthain Park) in Berlin. Drawn yellow curtains filled the room with a soft golden glow, symbolizing the yellow of sulphur, but also the contradiction of a domestic element (curtains) with the ruins of former residential buildings. Yellow is also a symbol of hope, loyalty, honor and new beginnings. In the opposite corner a desk of books, notes, maps, calculations, and other documents was illuminated with a desk lamp, representing the research involved in the department's work on WWII rubble soils. Historic maps and photographs found in the museum hung on the wall behind the desk. One map showed the planned deposition locations from Scharoun's post war urban plan, integrating the rubble moraines alongside garden colonies in the overall recreational green space planning. The installation was summed up as "a spatial analysis of WWII rubble deposition in Berlin, under consideration of sulphate leaching, recreational quality and collective memory."

Other than feedback from the workshop initiators and other participants, the reception of the work was limited due to the context of the exhibition. Rather than attract a large audience, the goal of the exhibit was to test out collaborative approaches and "translate" empirical experience into formal expression – interim results from a conceptual laboratory of knowledge gained. With a larger-scale public exhibition planned as a next step, several disciplinary and motivational ambiguities remain. In the words of one participating artist:

> "Questions about the motives of collaboration between art and (natural) science. . . and the internal and external conditions of such cooperation {remain}. . . Questions about the relationship between art and research, (research about art, research for art, research as art, {alternatively} art about research, art for research, art as research). . . Questions about the cognitive value of science and art and ultimately a discourse on art and science on the horizon of sustainability" (artist George Steinmann, in an E-mail to other participants on the 14. September, 2010).

Such concerns are furthermore reflected in the interviews with artists working with soils. Of the interdisciplinary experiences mentioned during the interviews, not much is known about what was gained on the scientist's end. While artists can help communicate information and inspire interest in soil research and protection, Stephen Wilson (2010 p.16) suggests that ". . .artists can help researchers become aware of unrecognized perspectives and cognitive frameworks, as well as help establish connections with audiences outside the research community." The question remains as to whether scientific partners indeed recognize new perspectives and cognitive frameworks by working with artists. In what ways do scientists integrate creative insight into their research, and can this be influenced by inter- or cross-disciplinary collaboration? Finally, do such partnerships tend to emerge from individual personalities that seek out specific competences, or rather by institutional structures and funding opportunities for interdisciplinary research? While much has been written on art engaged with scientific questions (Wilson 2010; Ede 2005) more research is necessary on the role of artistic knowledge and creative practice in the sciences.

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