

# Next Generation Water Sensitive Stormwater Management Techniques

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## Abstract

*Decentralized stormwater retention and infiltration in urban areas has been used in Germany since the beginning of the 1980s as a sustainable and cost effective alternative to combined and separate sewers. In Germany, all new developments are required by law to retain/infiltrate rainwater on site. Infiltration can help in returning the urban water cycle to its pre-urbanized state. Infiltration supports groundwater recharge, allows smaller diameters for sewers (resulting in cost reduction) and improves water quality of receiving waters because pollutants and high peak flow are effectively controlled. On the other hand, pollutants in runoff originating from domestic and industry emissions and traffic can contaminate soil and groundwater if they are not removed from runoff before it infiltrates into the ground. A wide variety of different infiltration systems exist, such as sinks, swales and gravel filled trenches, and have been used and investigated in Germany. Legal requirements and grants support alternative drainage techniques. After 20 years of operation not only the advantages, but also the problems and disadvantages of such systems can be identified, and new solutions, education programs and management tools developed. In conclusion, decentralized retention and infiltration is sustainable and cost effective. However, planning, construction and maintenance have to be undertaken in line with current best practice.*

## 1 Introduction and problem identification

The problem with existing drainage systems in Europe, which are commonly built as combined sewers, is that they are now endangering receiving waters. Furthermore, they are subject to cost explosion due to enforcement of strict permissible limits for combined sewer overflows and the need to install large tanks, basins and soil filters. During periods of dry weather, wastewater is cleaned in treatment plants and normally does not affect receiving waters. But during rain events large quantities of runoff occur, which cannot be adequately handled by wastewater treatment systems. In these circumstances, the efficiency of treatment plants decreases and water is discharged directly into receiving waters. Severe rain events cause flooding because rain cannot infiltrate through sealed surfaces in urban areas as would occur under natural conditions. This can cause substantial damage and financial loss to rivers and settlements respectively. There is widespread agreement that more frequent and intense rain events are likely in the future. The new European water policy, which came into force in 2000, contains a single piece of framework legislation to resolve these problems.

In response to this, the European Commission presented a Proposal for a Water Framework Directive with the following key aims:

- expanding the scope of water protection to all waters, surface waters and groundwater achieving "good status" for all waters by a set deadline;
- water management based on river basins;
- "combined approach" of emission limit values and quality standards;
- getting prices right;
- getting the community more closely involved; and
- streamlining legislation.

Much progress has been made in water protection in Europe, but Europe's waters are still in need of increased efforts to get them clean or to keep them clean. After 25 years of European water legislation, this demand is expressed, not only by the scientific community and other experts, but to an ever increasing extent by community and environmental organizations.

In the natural water cycle in Germany, for example, only 7% of rainfall leaves the catchment by surface runoff. The rest of the water is temporarily stored, infiltrated to the groundwater (31%) and evaporated and transpired by the plants (62%). In an urban catchment, almost all the water leaves as surface runoff via storm or combined sewers with high dynamic action (Figure 1). Only a small proportion of the water is infiltrated into the groundwater or evaporates. Clearly, such drainage systems are not sustainable.

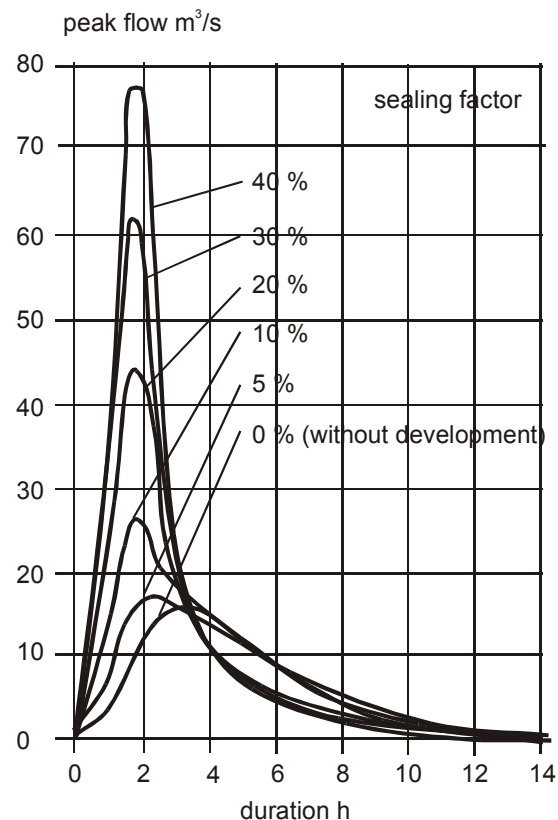


Figure 1: Change of peak flow by surface sealing (Emschergenossenschaft 1989)

The main goal of new water sensitive stormwater management techniques is to find sustainable and cost effective methods to copy nature. Water must be retained directly where runoff occurs. Discharge into rivers or lakes should only take place after retention and treatment of runoff, so that receiving waters are not in danger. The best way to manage water in the city is to make it visible to the community. Water should be collected and drained in open gutters before it is discharged into an infiltration device or a storm sewer. Water sensitive design not only means protecting our water resources, but also improving living conditions in our often sterile cities.

## **2 Pollutants and nutrients in urban runoff**

In addition to the problems of flow dynamics mentioned in section 1, stormwater contains pollutants and nutrients, which can endanger soils, groundwater and slowly flowing receiving waters when it is discharged. Whole ecosystems can be affected, when runoff is discharged directly without retention and treatment. Harmful constituents are emitted by industrial production, traffic etc. and are transported in the atmosphere. Rain contains sulphate, chloride, ammonia and phosphate in remarkably high concentrations. After Xanthopoulos and Hahn (1992), the inorganic nitrogen and phosphorous in rain show lower concentrations than the organic substances. They are not dangerous for soil and groundwater, but are harmful for receiving waters.

Gaseous sulphur oxides, ( $\text{SO}_x$ ), nitrogen oxides ( $\text{NO}_x$ ) and chloride (Cl) form acids in the atmosphere and affect the pH of stormwater. By reducing  $\text{SO}_2$  emissions from power plants and industry, the pH in stormwater in Europe has decreased since the 1920s (Georgii et al., 1983). During the last two decades, pH levels have further decreased due to desulphurisation of exhaust emissions.

In addition to atmospheric contaminants, pollutants can also be emitted by roof material. The influence of roof material and dynamics of rinsing off have been well examined (Förster 1996, Geiger et al. 1999). PAH, lead and copper show the highest pollutant concentrations from non-metallic roofs. Runoff from roofs shows a first flush of pollutants. Rainwater gutters and gutter-pipes often consist of zinc coated sheet or copper and can also adversely influence water quality. Metal roofs usually show highest concentrations of heavy metals (Priggemeyer 1998). Table 2 shows the range of concentrations of nutrients and heavy metals in roof runoff from more than 50 different long term investigations. For comparison, the concentrations of permissible limits of the Federal Law for Soil Protection in Germany are quoted in Table 3. Since values for most constituents are clearly exceeded, cleaning of roof runoff is necessary before rainwater can be discharged.

Infiltration or discharge from metal roofs without prior cleaning will inevitably result in soil or sediment contamination in the long run. Concentrations from metal roofs can be as high as 33 mg/l for copper, 61 mg/l for zinc and 24 mg/l for lead. The proportions of dissolved species are between 26 % for lead and 61 % to 90 % for zinc. These dissolved parts cannot be removed mechanically by filtration or sedimentation, so special cleaning measures must be undertaken (ion exchange, precipitation).

Table 1 shows the concentrations of pollutants and nutrients taken from more than 60 investigations in Europe (average mean event concentrations). The table shows the variability of concentrations in rain and in roof and traffic runoff. Table 2 also gives permissible limits for drinking water and seepage in Germany. Most concentrations in runoff exceed these values, so runoff cannot be infiltrated without prior cleaning.

Table 1: Range of nutrient and pollutant concentrations in rain, roof runoff and runoff from traffic surfaces

substance	unit	rain		roof runoff		road runoff	
		min	max	min	max	min	max
<b>physico-chemical parameters</b>							
el. cond.	[uS/cm]	28	223	25	269	108	2436
pH	[-]	3,9	7,5	4,7	6,8	6,4	7,9
<b>sum parameters</b>							
TSS	[mg/l]	0,2	52	13	120	66	937
BOD <sub>5</sub>	[mg/l]	1,0	2,0	4,0	16,1	2,0	36,0
COD	[mg/l]	5	55	5	96	63	146
<b>nutrients</b>							
P <sub>tot</sub>	[mg/l]	0,01	0,19	0,06	0,50	0,23	0,34
NH <sub>4</sub>	[mg/l]	0,1	2,0	0,1	6,2	0,5	2,3
NO <sub>3</sub>	[mg/l]	0,1	7,4	0,1	4,7	0,1	16,0
<b>heavy metals</b>							
Cd	[µg/l]	0,1	3,9	0,2	1,0	0,3	13,0
Zn	[µg/l]	5	235	24	4.880	120	2.000
Cu	[µg/l]	1	355	6	3.416	97	104
Pb	[µg/l]	2	76	2	493	11	525
Ni	[µg/l]	1	14	2	7	4	70
Cr	[µg/l]	2	8	2	6	6	50
<b>ions</b>							
Na	[mg/l]	0,22	20,00	-	-	5,0	474,0
Mg	[mg/l]	0,03	0,33	-	-	1,0	1,4
Ca	[mg/l]	1,10	67,13	1,00	19,00	13,7	57,0
K	[mg/l]	0,46	0,65	-	-	1,7	3,8
SO <sub>4</sub>	[mg/l]	0,56	14,40	-	-	5,1	139,0
Cl	[mg/l]	0,20	5,20	-	-	3,9	669,0
<b>organic substances</b>							
PAH	[ug/l]	0,04	0,76	0,35	0,60	0,24	17,10
HC	[mg/l]	0,29	0,41	0,108	3,14	0,51	6,50

Runoff from traffic areas contains higher pollutant concentrations than roof runoff. Pollutants from traffic include abrasion of vehicle tyres and brake linings (rubber, heavy metals, oxides), dripping losses (fuels, engine and transmission oil, grease, brake fluid, antifreeze), emissions from engines, corrosion products as well as road abrasion (Klein 1982, Sieker and Grottker 1988). Main pollutants in tyre abrasion are rubber, soot and oxides of zinc, lead, chromium, copper and nickel. The organic components are slowly degradable and liable to lead to contamination (Muschack 1989).

Table 2: Permissible limits for potable water and seepage in Germany

		potable water	seepage
Cl	[mg/L]	250	-
SO <sub>4</sub>	[mg/L]	240	-
Cr	[μg/L]	50	50
As	[μg/L]	10	10
Pb	[μg/L]	10	25
Cd	[μg/L]	5	5
Cu	[μg/L]	2000	50
Ni	[μg/L]	20	50
Zn	[μg/L]	-	500
PAH (EPA)	[μg/L]	0.1	0.2
HC	[μg/L]	-	200

### 3 Stormwater infiltration techniques, a critical review

The stormwater problem (peak flows and pollutants) can be solved in a sustainable way. Stormwater must be retained (stored) in the urban area itself and then discharged into receiving waters or infiltrated into the groundwater. With this approach, the water cycle can be moved closer to its original state. Receiving waters are not threatened by high peak flows and pollutant concentrations. Pollutants are controlled at source. Sewers and stormwater basins can be made smaller, with substantial cost savings. The following section outlines the systems commonly used since the 1980s in Germany, their function and their problems.

#### 3.1 Infiltration without storage, permeable pavements

Permeable pavements with reservoir structures are particularly appropriate for traffic areas. Four different types of permeable pavements are currently used in Germany. The first type consists of concrete pavers with wide joints or apertures to infiltrate the water underground. Pavers with canals on their sides are especially interesting (Figure 2a). The joints of these pavers are filled with a permeable mineral material that permits fast water movement. Because of these canals, the pavers need only narrow joints. This feature allows them to be used, for example, around supermarkets with shopping trolleys. Such pavements look very much like traditional pavements.

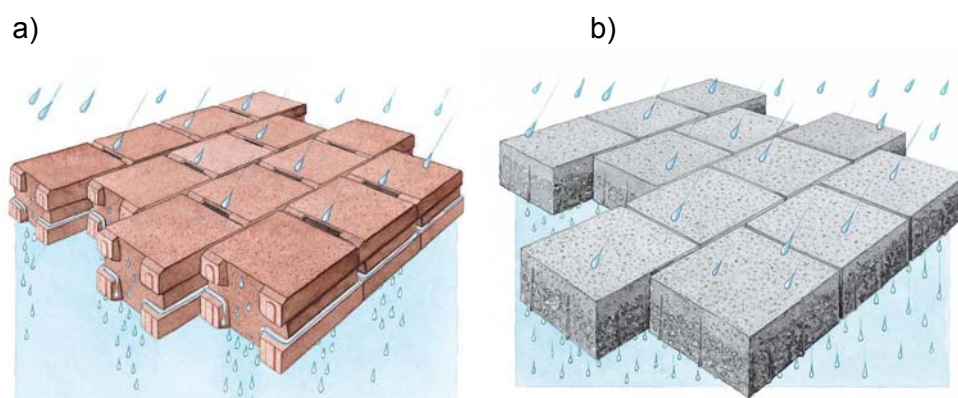


Figure 2: Systems of permeable pavements, a) pavers with canals and b) porous pavers

High pollution retention capacities can be achieved with paving-stones made of special porous concrete (Dierkes 1999). The system consists of a porous paver with two layers (Figure 2b). The top, fine layer acts as a filter for pollutants. The high porosity provides good infiltration and air exchange with the underlying soil. Particulate matter from rain, the atmosphere and vehicles is trapped in the upper 2 cm of the paver and can be removed by cleaning. The third system consists of porous paving-stones with greened apertures. This system is suitable for areas, where a natural look is desired. The small apertures of 3 cm x 3 cm are filled with a specific substrate that stores water, so that the grass does not dry out during rain-free periods. The open structure of the pavers prevents over-heating of the pavement, so the grass has ideal living conditions (Figure 3a). Finally, there are concrete pavers, which are made with spacers that provide larger gaps between each paver when laid in position. These joints are filled with a substrate that stores the rainwater and nourishes the grass during dry periods (Figure 3b).

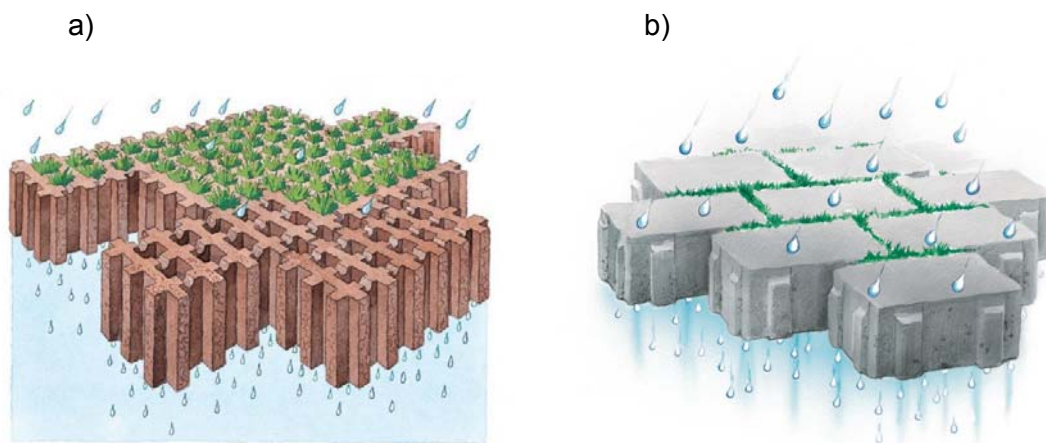


Figure 3: Systems of greened permeable pavers, a) small apertures, b) wide joints

- ◆ The worst problem with permeable pavements is clogging. Experience over the past 20 years suggests that most pavements clog between 5 and 10 years after construction. When this happens, water discharges over the surface and the advantages of the system are lost. On the other hand, the clogging particles contain most of the pollutants, so it is necessary that they are retained on the surface and cannot reach the soil or groundwater.
- ◆ The solution to this problem is regular cleaning of the pavements, enabling pollutants to be removed from the system.
- ◆ Other problems are structural damage of the surface or the road bed caused by the use of incorrect sub-base materials. During water storage, the sub-base must take the traffic loads. When incorrect material is used, small particles can flow in the road bed and cause structural problems.
- ◆ To solve this problem it is necessary to test the sub-base materials with the California-Bearing Ration test under water storage. Sufficient bearing capacity for the roadbed can be guaranteed if after 4 hours of testing the bearing capacity reaches at least 50 %.

Permeable pavements show very high efficiency in their ability to trap dissolved heavy metals in runoff. The pavement itself is responsible for much of the retention. Most metals are precipitated in the upper 2 cm of the porous concrete (Dierkes et al. 1999). But the *pH* in effluent shows, that the buffer capacities of concrete are very high, so that heavy metals do not occur predominantly in dissolved form.

With a newly developed cleaning device the problem of clogging can be solved. The cleaning device works as a high pressure cleaner with direct vacuum suction (Figure 4). The vehicle has a length of 6.38 m, a width of 1.80 m and a height of 2.68 m. It is equipped with a freshwater tank with a volume of 1,800 l and a sludge tank of 4,000 l. The power of the high-pressure-nozzles can be controlled in a continuous gradient from 150 - 300 bars. The suction capacity is 10,000 m<sup>3</sup>/h at a velocity of 73 m/s. Using a self-steering rear-axis, the vehicle is very mobile. To supplement the fixed cleaning module attached to the front of the vehicle, a small hand cleaning module with a tube of 15 m is provided. With this device, less accessible areas can be reached.



Figure 4: Cleaning vehicle

To assess the cleaning efficiency of the machine for porous pavements, the infiltration rate of a surface of a schoolyard was tested before the cleaning operation. Measurements were carried out with a drip-infiltrometer. At all points, the infiltration capacity was below 1 mm/(s·ha), so the pavement was completely clogged and could not infiltrate rainwater effectively. After the cleaning procedure, measurements of the infiltration rate at the three selected points were repeated. The new infiltration capacities were very high - between 1545 l/(s·ha) and 5276 l/(s·ha). The values shown in Figure 5 are all much higher than the level required ie 270 l/(s·ha).

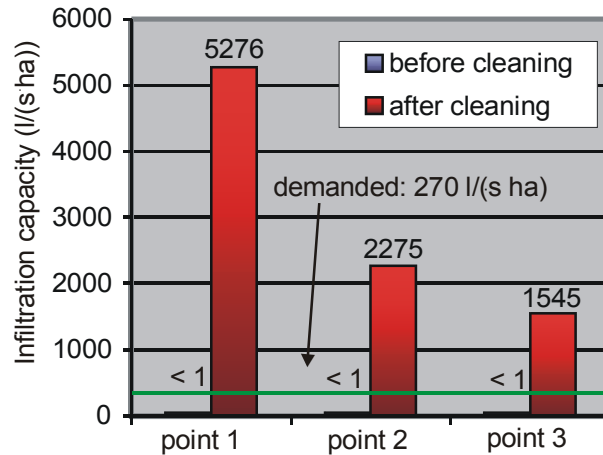


Figure 5: Comparison of infiltration rates before and after cleaning of the pavement

In conclusion, the tests showed that the infiltration capacity before and after the cleaning procedure with the newly developed cleaning vehicle could be raised from 1 litre/(s·ha) to more than 1500 l/(s·ha). It is clear, therefore, that German regulations for permeable pavements can be met and that regular cleaning of pavements can ensure life time infiltration capacities.

### 3.2 Infiltration with over ground storage, swales and basins

Swales are grassed waterways with side slopes flatter than 3:1 (horizontal : vertical), and top width to depth ratios of approximately 6:1 or greater. The runoff is filtered by the soil and pollutants are removed effectively. Large amounts of water infiltrate towards groundwater levels but evaporation also takes place. Basins are larger swales for centralized solutions.



Figure 6: Example of swale with wrong design parameters

Most of the infiltration devices in Europe are swales, because they are easy and very cost effective to build. Landscapers particularly favour swales, because it is easy to integrate them into the urban environment. On the other hand, many swales fail because:

- ◆ Difficult climatic conditions inhibit plant growth, the swales look ugly, and erosion and clogging problems occur;
- ◆ Soil permeabilities are not measured exactly, so dimensions are invariably wrong. Many swales show overflows and make no sense as drainage systems (Figure 6);
- ◆ Pollutant concentrations in the soil rise when runoff from roads or metal roofs is infiltrated. Soil therefore must frequently be replaced;
- ◆ Swales are built too close to buildings, so damage by infiltrating water may be observed;
- ◆ Swales restrict land use and are often unsuitable for small garden areas. Misusing swales as playgrounds, results in soils becoming compacted and not allowing water to infiltrate; and
- ◆ If swales alongside roads are used as car parks and for dumping waste, they must be fenced off if they are to operate properly.

### **3.3 Infiltration with subsoil storage, trenches and pipes**

Underground infiltration facilities do not constrain land use. Furthermore, they are not endangered by vandalism, which can be important. With facilities situated underground, infiltration is provided by a permeable artificially-constructed gravel filter trench, which is covered by shallow soil or by pavement. The pore volume of the gravel allows for substantial storage capacity. When retention is the main purpose of the trench, runoff is either infiltrated from the reservoir into the underlying and surrounding soil, or is collected by perforated pipes and routed to a throttled outflow facility. Surface trenches accept diffuse runoff directly from adjacent areas after it has been filtered by a grass buffer. Underground trenches require installation of special inlets to prevent coarse sediments and oil/grease from clogging the reservoir.

The percolation trench should be filled with crushed stone or gravel. This system is especially effective for soils with low hydraulic conductivity and for hot climates. Most of the runoff is infiltrated, so it is very effective in supporting groundwater recharge, for example to decrease salinity. The system can easily be combined with infiltration swales.

Infiltration can also be performed by perforated pipes, which are covered by shallow topsoil or, in the case of roads or car parks, by pavements. The pipe volume gives substantial storage capacity. Pipes with different diameters can be used. Parallel pipes or star-shaped pipes can be arranged to increase the infiltration capacity. Underground pipes require installation of special inlets to prevent coarse sediments and oil/grease from clogging the soil around the pipe.



Figure 7: Installation of a drainage pipe

### Problems

- ◆ Infiltration sinks, pipes and trenches are sensitive to clogging, especially when runoff is not cleaned to remove particles.
- ◆ Most facilities are situated underground and cannot be cleaned, because diameters of pipes are too small.
- ◆ Pollutants are not removed like in soil passages, so groundwater can be endangered over time.
- ◆ Gravel or crushed stones used as trench fill have insufficient pore volume, the devices are too small.

### 4 Examples for large facilities

Sustainable drainage methods are state of the art in Germany and in many other European countries and help in achieving the aims of the new European Water Policy. In view of this, water authorities encourage disconnection of large areas from existing drainage systems. In most States in Germany, newly developed properties are required to infiltrate runoff or to retain and discharge it into nearby receiving waters. New developments have no discharge of runoff if the soils and hydrogeological conditions are suitable. On the other hand, infiltration is a good method to save costs when renewing old combined sewer systems. The Ministry of Environment in Northrhine Westphalia gives grants for disconnected impermeable areas:

- ◆ 15 € per sqm disconnected area from the combined sewer system
- ◆ 15 € per sqm infiltration area (swale, basin, trench, trough-trench-system)
- ◆ 15 € per sqm of green roofs.

Additional grants are available for stormwater harvesting facilities (up to 1500 €).

With this legislative requirement and the promotion program, many areas are being disconnected from existing sewer systems. Other local water authorities are now introducing grant programs. In reconstructing damaged sewers, it is generally cheaper to use a liner in the old sewer and to install a separate system to deal with stormwater runoff.



Figure 8: Left: Eco buildings (low energy consuming, greywater reuse) with green roofs, permeable car parks, infiltration pipes for the roof runoff, Right: Permeable car park in front of a furniture store



Figure 9: Left: Large bus park and Right: school yard with permeable pavements

Figures 8 and 9 show examples of projects which use porous pavers. Figure 8 shows an environmental building development in Coesfeld, Germany. The concept of the building was to keep emissions as low as possible. Heating is provided by a central combined heat and power plant in the city. The buildings have a low energy rating and have green roofs to retain the water directly. Stormwater runoff from the roofs is infiltrated by permeable pavements. Roof runoff is infiltrated by an underground infiltration system and greened areas can be used as playgrounds. The picture on the right in Figure 8 shows a large car park in front of a familiar furniture store. All the stormwater from the car park is infiltrated using permeable, greened pavers. Figure 9 shows other

applications for porous pavers. The picture on the left shows a bus park in Kevelaer, Germany, while the picture on the right, a schoolyard. Drainage areas in these examples, none of which use additional surface drainage systems, range from 5,000 – 20,000 m<sup>2</sup>.

## 5 Infiltration and the effects on groundwater

The sealing of surfaces in urban areas dramatically alters the water cycle. Under natural conditions in Germany – diagram on the left in Figure 10 - about two thirds of the stormwater evaporates. Only one sixth, together with some of the surface runoff, contributes to overall groundwater recharge. With an increase in surface sealing – as shown in the diagram in the middle - surface runoff rises up to two thirds. Less water evaporates. The amount of natural groundwater recharge is reduced to nearly zero. But if the entire surface runoff is infiltrated into the subsoil through infiltration systems – as in the diagram on the right - the amount of groundwater recharge rises as compared to natural conditions. Since the rate of groundwater recharge is almost doubled, the groundwater table might rise. A higher groundwater level can cause problems such as wet cellars and raising of impermeable constructions.

The increase of groundwater recharge depends on the following factors: 1) *the amount of rainwater*. In Germany, rainfall ranges between 400 and 1000 mm/year 2) *the infiltration rate*. If only every second house has an infiltration system, the increase in groundwater recharge is minimal. The extent of surface sealing and development area has only a small effect.

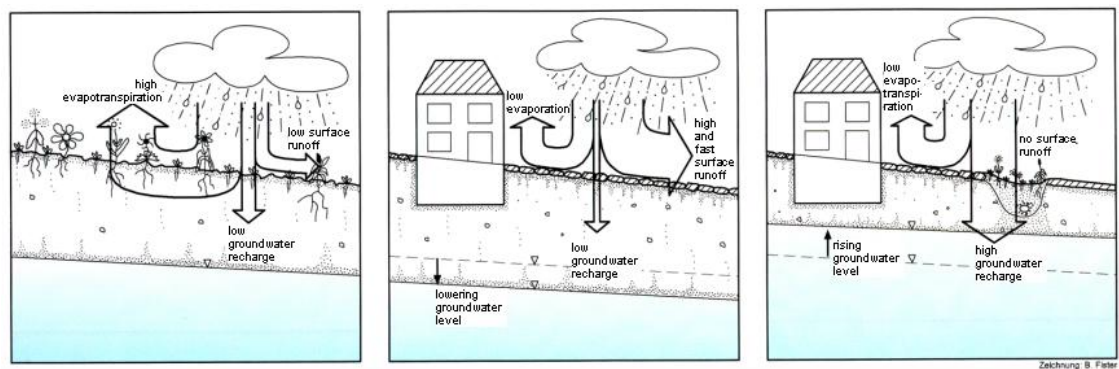


Figure 10: The water cycle under natural conditions and in an urban area (after Geiger & Dreiseitl 2001)

Figure 11, which is based on studies conducted by the Universities of Muenster and Essen (financially supported by the Ministry of the Environment and Conservation, Agriculture and Consumer Protection of the State Northrhine-Westphalia, AZ: IV-9-042234), maps the influence of rainwater infiltration on groundwater recharge. Light grey (or green) indicates those areas with low groundwater recharge rates while dark grey (or red) indicates high recharge rates. Dark colours (or pink) in the margins of the map denote areas under natural conditions used by farming and show recharge rates of between 251 mm and 300 mm per year. If an urban area under development is simulated, groundwater recharge is likely to be reduced.

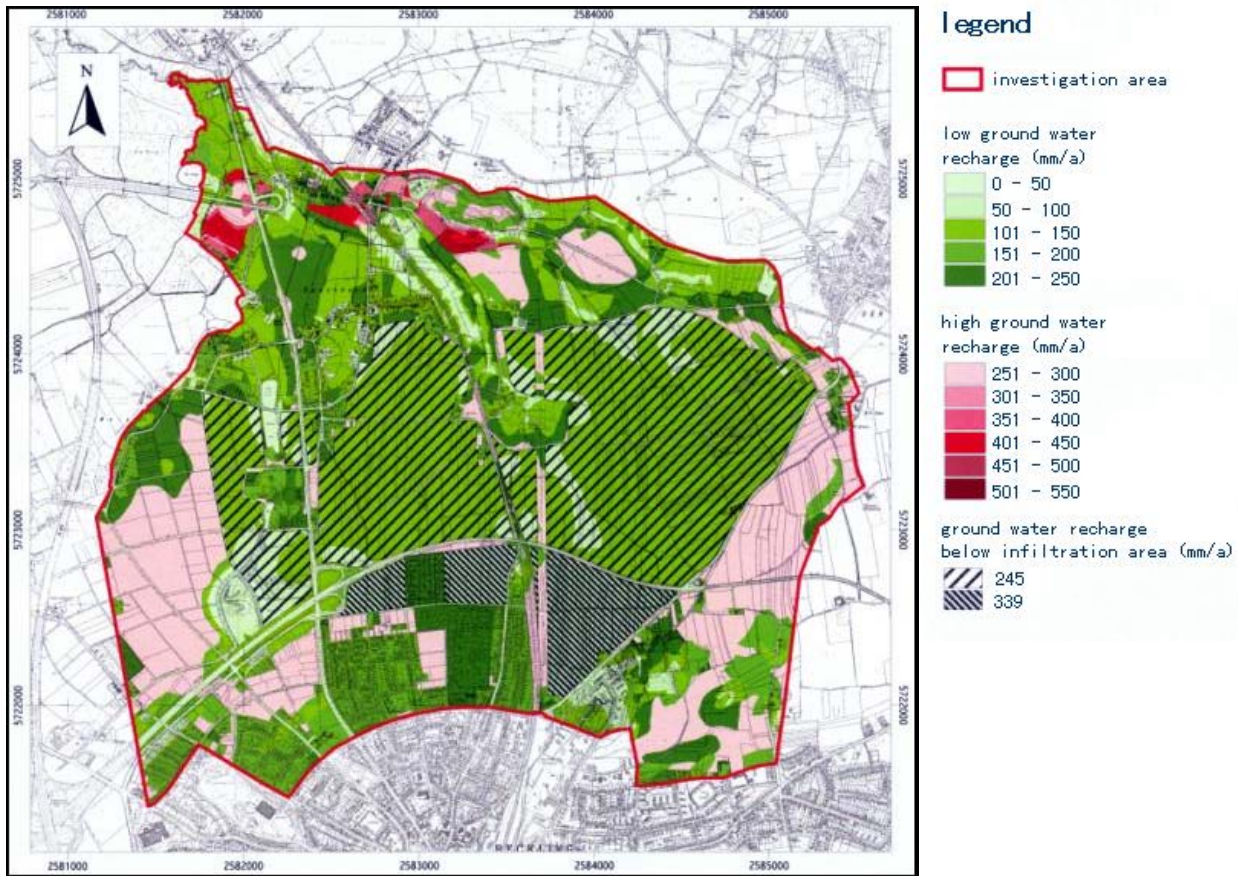


Figure 11: Influence of stormwater infiltration on the groundwater (Geiger & Coldewey 2001)

Outside the area covered by infiltration systems, it can be seen that medium surface sealing reduces groundwater recharge by half - from 251 mm / 300 mm per year in the natural state to 101 mm / 150 mm per year. Groundwater recharge on sites to the south with a high degree of surface sealing is no more than 50 mm / 100 mm per year.

If total roof runoff is directed to infiltration systems, groundwater recharge increases substantially. On sites with medium surface sealing, groundwater recharge increases by about 245 mm to more than 350 mm per year. This is three times greater than for sealed surfaces and an increase even over the natural state. On sites with a high degree of surface sealing groundwater recharge increases about 339 mm to about 400 mm per year. This means that, compared to the sealed state, groundwater recharge is eight times higher and double that applying in the natural state.

How does the increase of groundwater recharge affect the groundwater level? To evaluate this, a numerical groundwater model with a program based on the finite element method was used. The map on the right in Figure 12 shows the differences in groundwater levels, with significant changes evident up to 2.34 m. It is notable that the impact area has a wider extension than the development area, which is marked by the inner line (magenta). The differences decline closer to receiving water courses, highlighting the importance of water courses. This also indicates an increase of groundwater outflow / base flow with all ecological effects.

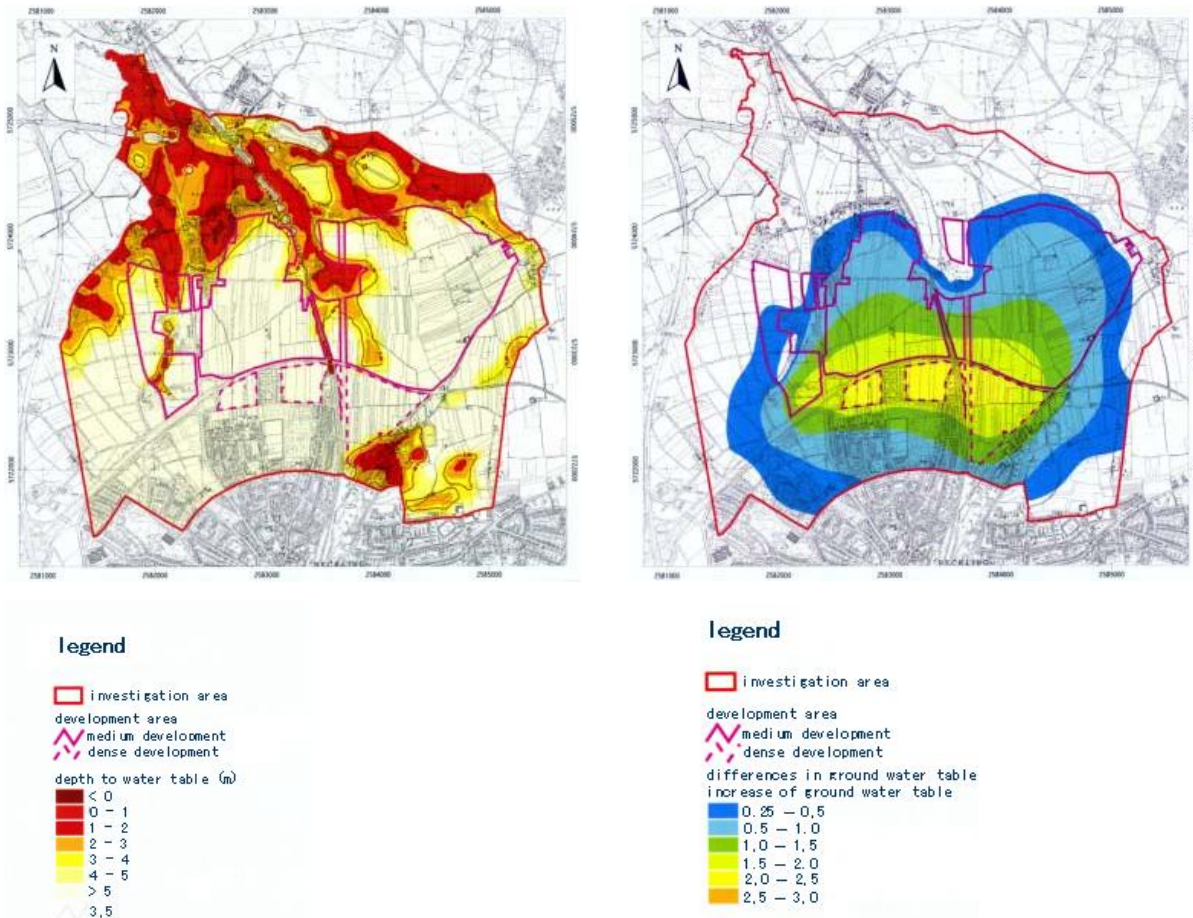


Figure 12: Changes in groundwater level by infiltration (Geiger & Coldewey 2001)

The map on the left in Figure 12 indicates groundwater levels. Depths are generally more than 5 m and therefore non-critical. Groundwater levels of less than 3.5 m (with rises of  $\pm 1$  m) must be considered as critical to basement flooding. These latter levels are marked as a thin line. This line partly occurs inside the development area.

In general, infiltration of rainwater is favourable to the environment but, as is clear from experience, has to be managed. This means that a considerable amount of information must be collected, if safe groundwater levels are to be maintained.

It is suggested that the following steps are necessary to plan a new development incorporating infiltration systems:

1. Assess the infiltration capacity of the soil - the hydraulic conductivity of the soil needs to be within the range  $1 \cdot 10^{-3}$  m/s and  $1 \cdot 10^{-6}$  m/s.
2. Check the groundwater level – this should be more than 2 m. Seasonal and long term variations in levels should be taken into account.
3. Install a groundwater monitoring system with measuring points distributed around the entire urban area and especially around development areas.

4. Undertake an extensive hydrogeological assessment to receiving water courses.
5. The function of receiving water courses and even the function of leaky sewer systems has to be controlled.
6. When calculating the urban water budget of a site, estimate the amount of infiltration according to the decrease of groundwater recharge due to projected soil sealing.
7. Groundwater modelling is an effective method for calculating groundwater flow and groundwater levels in regions with existing conflicts.

## 6 Summary

Rainwater retention and infiltration in urban areas is a sustainable alternative to traditional drainage systems such as combined and separate sewers. Infiltration can help in returning the urban water cycle to its pre-urbanized state. In Germany, infiltration is enforced by law for all new developments. Infiltration supports groundwater recharge, can decrease groundwater salinity, allows smaller diameters for sewers (hence reducing cost) and improves water quality of receiving waters because pollutants and high peak flows are effectively controlled. On the other hand, pollutants in runoff originating in domestic and industrial emissions as well as traffic endanger soil and groundwater if they are not removed from runoff before it infiltrates underground. A wide variety of infiltration systems exist and have been used and investigated in Germany since the beginning of the 1980s. Legal requirements and grants support sustainable developments in urban drainage. However, many facilities have failed over the past two decades, because of errors in planning, construction and maintenance. These errors have been analyzed and have led to new approaches and better solutions. Decentralized retention and infiltration systems can clearly help to improve the quality of receiving waters and groundwater and reduce costs.

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