Management of Stormwater on Highways

by

Anna-Lisa Pfeffermann, B. Eng

Thesis

for attainment of the academic degree of

Master of Engineering

(M. Eng.)

Presented to the Faculty of Architecture and Civil Engineering

of the Hochschule **RheinMain,** University of Applied Science

Wiesbaden

2011

Thesis Advisor: Prof. Dr.-Ing. Heinz Eckhardt

Second Reader: Dipl.-Ing. (FH) Paul Guckelsberger

I affirm that I have written the dissertation myself and have not used any sources and aids other than those indicated.

Date / Signature: ______________________________

Hochschule RheinMain • RheinMain University of Applied Sciences
Wiesbaden - Rüsselsheim - Geisenheim

Fachbereich Architektur und Bauingenieurwesen

Masterthesis im Studiengang UMSB für Frau Anna-Lisa PFEFFERMANN

Management of Stormwater on Highways

Problem description:

The Project MASH is an European project focusing on the different situation of stormwater management in seven European countries. The Hochschule Rhein-Main is cooperating with the „Landesanstalt für Strassen- und Verkehrswesen Hessen“ and is responsible for the transfer of good practices from the region of Hessen to less experienced regions in Europe. The RheinMain University in the moment is preparing steps to describe the legal situation, monitoring programs and the different treatment options in the sixteen federal states. This Master thesis is cooperating with the two project works of Mr. Waltz and Mr. Ceko.

Objectives:

- Literature- and internet-study, screening of research on the field.
- Description of the legal situation in Europe and Germany. In detail description of the situation in the federal states:

  Sachsen, Sachsen-Anhalt, Thüringen, Brandenburg, Mecklenburg-Vorpommern und Berlin.
- Together with the results of Mr. Ceko and Mr. Waltz description of the main points in the legal situation of the sixteen federal states.
- Summary of monitoring programs, compounds in runoff and relations to the intensity of traffic.
- Together with Mr. Ceko and Mr. Waltz description of the state of technic in the treatment of runoff.
- In detail description of the best practice focusing of

  „mechanical treatment“ and „treatment of high polluted runoff“.

  Summarizing and evaluating the main results of the best practices from Mr. Waltz and Mr. Ceko and from the own research.
- Evaluation of the results, summary and outlook of project steps to come.

Prof. Dr. H. Eckhardt　　Prof. Dr. R. Eger　　Dipl.-Ing.P. Guckelsberger

Contents

List of Figures

List of Tables

List of Abbreviations and Symbols

A	surface
A_F	filter area
AOX	Adsorbable organic halogen compounds
ATV	Abwassertechnische Vereinigung (=Wastewater Treatment Association)
A_U	connected area
BOD	Biochemical Oxygen Demand
BWA	Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (=Association of Engineers for Water Management, Waste Management and Land Improvement)
Cd	Cadmium
COD	Chemical Oxygen Demand
Cr	Chrome
Cu	Copper
d	diameter
DIBt	Deutsches Institut für Bautechnik (= German Institute for Building Technology)
DIN	Deutsches Institut für Normung (=German Institute for Standardization)
DOC	Dissolved Organic Carbon

DTV	Daily Traffic Volume
DVWK	Deutscher Verband für Wasserwirtschaft und Kulturbau (=German Association for Water Management and Land Improvement)
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (=German Association for Water, Sewage and Waste)
E. coli	Escherichia coli
e.g.	for example (=exempli gratia *lat.*)
EPA	Environmental Protection Agency
et al.	et aliii (masculine); et aliae (feminine); et alia (neuter)
F_A	Buoyancy
F_g	Gravity
F_R	Resistance
h	height
ha_{red}	reduced surface
Hg	Mercury
i.e.	that is (=id est *lat.*)
L	horizontal settling path
MTBE	Methyl-Tertiary-Butyl Ether
N	Nitrogen
NA	not applicable

NH_4-N	Ammonium-nitrogen
NO_3-N	Nitrat-nitrogen
NOx	Nitrogen oxides
N_{tot}	total Nitrogen
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PCDD	Polychlorinated Dibenzodioxins
PCDS	Dibenzofurans
Pd	Palladium
Pt	Platinum
P_{tot}	total Phosphorus
Q	inflow
RAS-Ew	Richtlinie für die Anlage von Straßen – Entwässerung (=Guideline for the construction of roads – Drainage)
R_{crit}	critical rainfall
RiStWag	Richtlinie für bautechnische Maßnahmen an Straßen in Wassergewinnungsgebieten (=Guideline for structural measures on roads in water catchment areas)
SST	Stormwater Sedimentation Tank
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
t_s	settling time

TSS	Total Suspended Solids
t_v	flow time
TVO	Trinkwasserverordnung (=Drinking Water Regulations)
v	flow rate
v_s	settling velocity
w	width
wopS	without permanent storage
wpS	with permanent storage
WPZ	Water Protection Zone
Zn	Zinc

Terminology

englisch term	german term
area percolation	Flächenversickerung
batter	Böschung
combined sewer system	Mischsystem
ditch	Rigole
grit chamber	Sandfang
Lamella separator	Lamellenabscheider
lawn dump	Rasenmulde
vegetated	bewachsen
percolation	Versickerung
rake	Rechen
retention soil filter	Retentionsbodenfilter
runoff	Abfluss
screen	Sieb
scumboard	Tauchwand
seepage reservoir	Versickerungsbecken
separate sewer system	Trennsystem
settlement tank	Absetzbecken
shaft percolation	Schachtversickerung

soil zone	Bodenzone
stormwater holding tank	Regenrückhaltebecken
stormwater overflow tank	Regenüberlaufbecken
stormwater sedimentation tank	Regenklärbecken
stormwater tank retaining the first flush of storm water	Fangbecken
stormwater tank with overflow	Durchlaufbecken
tank peroclation	Beckenversickerung
top soil	Oberboden
trough	Mulde
vortex separator	Wirbelabscheider
wastewater treatment plant	Kläranlage
water body	Gewässer
waters	Gewässer

1 Introduction

1.1 Problem definition

In Germany, there is a highly developed network of arterial roads for long-distance traffic.

The local road network in Germany has a total length of 231,000 km [BMVBS, 2011]. In Germany a total area of 357,026.55 km² corresponds to a network density of about 0.65 km/km². Federal roads will play a central role and are of growing importance. They take over half of the annual mileage of the vehicles (in relation to its length of 23 % of the total road network) [BMVBS, 2011].

For freight transport and private motoring a significant increase is predicted until 2025 [ITP a. BVU, 2007]. In addition, an increasing intensity of use on the existing road surface is observed, because the use compared to the expansion progresses faster [DESTATIS, 2007], but also the development of transport infrastructure promotes the growth of traffic [UBA, URL; 07/26/2011]. Germany will have to respond to this, also because of its importance as a heavy frequented European transit country. Therefore Germany will need a new and expanding road infrastructure. The consumption plan until 2015 therefore provides the construction of 1,900 km of highways, the extension of another 2,200 km of highways[1] and the extension and construction of federal roads, including 850 km bypasses [BMVBS, 2011]. It was financed until 2010 demand action of more than 28 billion Euro, further 11 billion Euros for projects under construction are estimated [BMVBS, 2011].

In a review of the current consumption plan of the year 2004, the proven benefits against the background of the anticipated traffic growth until 2025 are generally confirmed [BMVBS, 2010]. In some regions, although there are stronger demographically-related traffic reductions and thus the use reductions, the economic benefit is not to question [BMVBS, 2010].

In the long term, scarce resources and the need to sustain them require the handling to be based on the preservation of road infrastructure [BMVBS, 2011]. The

[1] highway ≙ Autobahn (germ.)

UBA also points out that according to empirical studies the effect of new roads on the improvement of the economic performance of a region often is overestimated. Therefore in future primarily the rehabilitation, the noise abatement and the careful expansion of proven weaknesses and shortages must have priority [BMVBS, 2011].

In addition to the careful handling and a reduction of land use by traffic area, the emission control and air-pollution control is primary objective of environmental protection.

The use of motor vehicles leads to the introduction of pollutants. These pollutants are derived from abrasion and wear processes and cause damage/defects to vehicles and combustion processes. These substances are emitted into the air or settle on the road surface. During rainfall events, the pollutants are then washed out and, depending on material properties to imitate in surface water and ground water or accumulate in the soil passage.

With the progressive expansion and construction of traffic areas and the associated increase in road traffic, the harmful effects on the environment will increase.

Harmful effects, such as the road surface runoff must be counteracted. Therefore discharging stormwater must be cleaned and sensitive areas, such as water protection areas, need to be protected precautionary. The possible treatments of road runoff range from mechanical-technical, physical-chemical to natural or biological processes.

Many of these techniques have already been used successfully for a long time in the urban water management in combined wastewater systems. With the introduction of the separate system and further increasing requirements for wastewater treatments, the importance of centralized and decentralized procedures for stormwater treatment is growing. Even more so when the stormwater flows from developed to paved areas and then needs disposal, as it is sewage [WHG, 2009; § 59].

Pollutants contained in road surface runoffs such as heavy metals and their harmful effects are largely known and widely researched. By contrast, there are substances that are not fully investigated yet, such as polycyclic aromatic hydrocarbons (PAHs). Just as heavy metals, they are poorly degradable. New studies results provide evidence on the composition of substances while in road surface runoff and the effectiveness of existing processes used for their treatment.

With this gain in knowledge processes can be modified or re-engineered. Furthermore, a continuous exchange of practical experiences can help to choose appropriate procedures quickly and unerringly and thereby close out known sources of error from the beginning.

In each federal state of Germany, legal and technical requirements differ. In addition, general experience in the treatment or removal of road surface runoff is different. The now since March 2010 nationwide uniform full control of water rights harmonize so far in the state law in standardized ranges of water management and shifted issues in detail of the water management in the range of substantive and procedural law to the regulation level [Fröhlich, K., 2009]; [WHG, 2009; § 23].

By opening clauses, the states are still given opportunities to self-regulation. Substance- and facility-related regulations are exempted under § 72 para 2 GG. The Federal Water Act (WHG) and the provisions adopted regulations supersede state law only where it regulates itself concretely.

The EC regulations that are to be implemented are also relevant, as they will be binding. The requirements of the Water Framework Directive with the objective of good chemical and ecological status of water bodies require versatile action and an extension of the task performance water law.

The increased regulatory requirements and future adjustments of regulations will also give consideration to changes in the state of art of sewage disposal of street runoffs with it.

This may entail a continuous comparison of the local rules and an adjustment in federal law.

Even in an international comparison und exchange of experiences further knowledge could be gained that would prove beneficial for the sustainable and environmentally friendly development.

In addition to incorporate a progressive development of legal requirements, as well as the scientific knowledge necessary in the state of art, other factors apply and need to be considered, such as the projected effects of climate change in the planning and construction of sewerage systems to be considered.

Overall, a lively discussion in all environmental fields is required. Current studies show that ecosystem services provide an important, well-to-quantify economic contribution to the conservation of ecosystem structure and its function [TEEB, 2010]. The responsibility of the TEEB report first results of the study are from Germany [BfN, 2010], should be incorporated by the President of the Federal Agency for Nature Conservation Beate Jessel into all future water planning decisions [G+L, 2010].

A constructive cooperation across disciplines and national boundaries can make an important contribution to its future-oriented act in the interests of sustainability and the efficient use of limited resources.

1.2 MASH-Project

The EU will address a wide range of topics in the field of environmental standards. This project will contribute to finding solutions of the problems of our time. Current topics such as combating climate change, conservation of biological diversity, mitigation of environmental impacts and sustainable development [EU, URL; 06/22/2011] are going to be looked at. The project deals with the urgent tasks to safeguard the sustainable functioning of the ecosystem. The issues are not considered separately, but as being interlinked. Consequently, responses to problems will also be connected to each other and interaction is thereby made possible.

The management of road surface runoff is a common problem [Krusic, M., 2011]. The Member States of the EU must deal with this by common law in order to reach the European environmental goals, such as reducing pollution-related health problems and the responsible use of natural resources. In this sense, water management is a key issue for the realization of sustainable measures to protect the livelihood of water.

New research results in various European regions show the relevance to the pollutant discharges caused by road surface runoff. In the Member States there are very different legal requirements and technical standards. In addition, the experiences with the treatment process are very different. Some member states have only little experience in that area or none at all.

With the proposed EU project “Management of Stormwater on Highways” (MASH) an inter-European exchange of experiences of handling stormwater runoff of roads should be established [Krusic, M., 2011; section 2.1.1]. The duration of the project will be three years (approx. 01/2012 – 12/2014).

While the currently ongoing SHARP-project[2] focused on groundwater management, the estimated MASH-project is a specific extension to the results from SHARP.

As a result guidelines should be developed to make legal regulations on local and regional level possible. Moreover, the guidelines are intended to serve policy makers to raise awareness that road surface runoff from heavily traveled roads threaten the groundwater and contaminate and affect drinking [Krusic, M., 2011; section 2.1.1].

The MASH-project has the intended overall goal to handle road surface runoff more effectively by implementing three sub-goals to implement [Krusic, M., 2011; section 2.1.1; 2.1.3]:

- Part of the project is the intensive exchange of examples of good practice between countries with more experience (France, Netherlands, Germany, Austria) and those held with less experience (Italy, Slovenia, Poland). Thereby sustainable management of surface and groundwater will be promoted.
- Approaches and recommendations for possible action on local and regional policy level will be developed in order to reduce the task of the risks to the environment and further water pollution.
- The experiences made by regional cooperation should be integrated into policies. By incorporating the findings into the local and regional policies, they can be funded by the “European Regional Development Fund” (ERDF) in the future.

[2] SHARP is an EU funded project of international cooperation program INTERREG IVC (www.sharp-water.eu) for the protection and preservation of the groundwater; the INTERREG IVC program, thereby encouraging the cooperation of European regions to exchange experience and technical know-how and in innovation, economics, environment and risk prevention.

The urgency and the need for projects such as the MASH-project will gain particularly in regard to large area-scale expansion projects of the European road network have added significance.

1.2.1 *Relevance of European road projects*

In 1996 the European Council and European Parliament decided[3] on Community guidelines for the development of a trans-European transport network (TEN-T)[4]. The realization of the trans-European transport network should contribute to the smooth functioning of the internal market, to strengthen the economic and social cohesion. It includes the infrastructure (roads, railways, inland waterways, ports, airports, navigational facilities, transshipment facilities, pipelines) and the services that are necessary for the operation of infrastructures [EU, URL; 07/20/2011].

The road network is in accordance with the plans of the TEN-V constitutes part of the network for combined transport. It includes water roads and railways, which allows the pre- and /or terminal road, the connection and operation of all Member States [EU, URL; 07/20/2011].

The European commission has prepared a list of 30 priority projects that should be taken on before 2010. The total cost is estimated at 225 billion €. The majority of this fund will be directed towards railways and inland waterways; a small portion goes to road projects [EU, URL; 07/20/2011].

For the scope of the planned road projects within Europe under this study project no substantiated data could be determined. The priority projects of the TEN-V have little significance because of their small number and are probably not representative of the actual level of non-local and inter-European road projects.

Therefore the guidance and principles of the TEN-V are noteworthy. In addition to the promotion of a strong performance transport network the requirements of environmental protection are also considered in the planning and building of the network. In February 2009 the EU commission published a Green Paper on the future development f the TAN-V. The problems of nature protection should therefore be

[3] Decision No. 1692/96 EC (Official Journal L 288 of 09/09/1996)

[4] It includes the infrastructure (roads, railways, inland waterways, ports, airports, navigational facilities, transshipment facilities, pipelines) and the services that are necessary for the operation of Infrastructures

tackled better in the emergence of an integrated European transport system [EU, URL; 07/20/2011].

The White Paper of the EU commission for future European transport policy from March 2011 included more objectives for the further development until 2050. [EC, 2011]. It needs 40 initiatives to build a competitive European Economic Area to increase mobility in Europe. The key objectives until 2050 are [EU, URL; 07/28/2011]:

- to have no more conventional petrol or diesel cars in the cities
- 40 % CO_2 less fuels from renewable sources in air traffic and 40 % less CO_2 emissions in shipping
- relocation of the passenger and freight transport over medium distances from road to train and water to 50 %

Thus, until 2050 a total saving of CO_2 emissions in the transport of 60 % is sought [EU, URL; 07/28/2011].

The background for these new objectives is projected global changes, like climate change and the related development of energy policies. It remains to be seen whether the targets will be fully achieved and what challenges are taken on this path. The fact is that changes in the types of motor vehicles and a greater expansion of public transport or the restructuring of freight and passenger traffic today perceived environmental tasks, such as a safe disposal of road runoff can change in their task. Likewise, there are also the challenges from today preparing the way to the future.

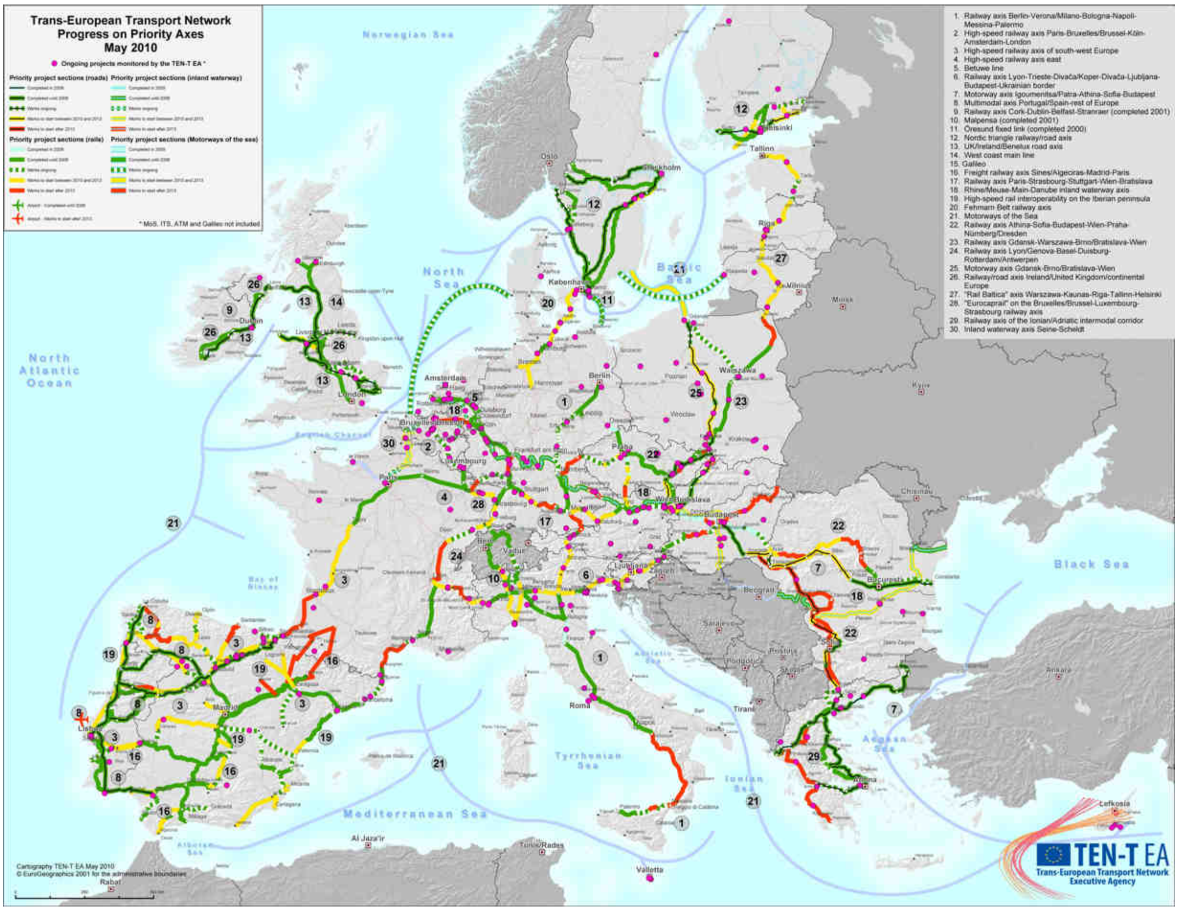

Figure 1 Trans-European network of different types of traffic in construction and planning [EU, URL; 06/22/2011]

1.3 Objective

With the MASH-project “Management of Stormwater on Highways”, the legal and treatment-technical frameworks in seven EU countries are worked out and communicated in order to develop proposals for “best practice”-technologies.

At the University of Applied Sciences RheinMain preparatory work for dealing with the issue in the Federal Republic of Germany is done (as part of the project). The cooperation partner of the University of Applied Sciences RheinMain in this context is the State Institute of Highway and Transportation Hesse, Wiesbaden. Together with the parallel project works of Mr. Rene Ceko and Nicolas Waltz the legal frameworks, monitoring programs and treatment technologies in the sixteen federal states should be examined.

1.4 Layout

This thesis is a collaboration with the interdisciplinary project of Mr. Waltz and Mr. Ceko [Waltz, N.; Ceko, R., 2011]. The edited portions in this interdisciplinary project were used without appropriate identification. The work distribution is shown in Figure 2.

Management of Stormwater on Highways

Stormwater on Highways

•	Anna-Lisa Pfeffermann

Legal Framework

• EU law	René Ceko
• Law of the Federal Republic of Germany	René Ceko
• Law in the federal states	Pfeffermann, Ceko, Waltz
• Regulations and standards	René Ceko

State of the art

• Mechanical Treatment	Anna-Lisa Pfeffermann
• Stormwater Treatment by Filtration	René Ceko
• Chemical and Physical Treatment	René Ceko
• Nature-orientated Treatment	Nicolas Waltz
• Treatment of Highly Polluted Stormwater	Anna-Lisa Pfeffermann

Best Practice

• The situation in the federal states	Pfeffermann, Ceko, Waltz
• Comparison of the methods	Pfeffermann, Ceko, Waltz

Special aspects of environmental legislation

•	Nicolas Waltz

Monitoring

•	Waltz, Ceko

Final discussion and outlook

•	Pfeffermann, Ceko, Waltz

Summary

•	Pfeffermann, Ceko, Waltz

Figure 2 Structure of the thesis with respective editors

In the beginning the constitution and contents of the road surface water are discussed. The thesis covers the German transportation network, the precipitation types and quantities and the ingredients. Especially the last point is discussed extensively and various investigations are shown because of their implications for the treatment requirements of the road surface water. In addition the relationship between pollution level, traffic volume and possible other dependencies is considered.

The next point is the legal framework. It starts at the EU level and goes down to the federal state level. Here each individual state is considered, which additional rules or policies or guidelines exist internally and which special provisions are included in terms of road drainage in it. The investigation of the states is divided. Schleswig-Holstein, Mecklenburg-West Pomerania, Berlin, Brandenburg, Saxony and Saxony-Anhalt are treated in this thesis. The remaining states are taken from the interdisciplinary project by Mr. Waltz and Mr. Ceko [Waltz, N.; Ceko, R., 2011]. In the last part of this chapter it will be discussed regulations and standards. Here, the relevant EN and DIN standards, the guidelines of the RAS, as well as advisory leaflets and work sheets of the DWA and the BWL leaflets are taken into consideration.

Subsequently, the current state of the art is shown. Common treatment methods of how to deal with stormwater on highways are presented. These are subdivided into the mechanical treatment, the treatment by filtration, the chemical and physical and the nature-orientated treatment and the treatment of heavily polluted stormwater. The construction, operation, application areas and opportunities of the methods are explained.

Furthermore the situation of stormwater treatment in the individual states is now presented. Again, the distribution of work is analogous to chapter 3.2. The aim is to present the most widely used methods in the federal states and the why they are used. After that a comparison of the methods is made in order to demonstrate potential advantages and disadvantages and to possibly work out preferable methods.

The next chapter (chapter 6) is dedicated to the monitoring. Here is a definition of the term, legal aspects are addressed and the situation or the state in the individual states is presented.

The last chapter (chapter 7) is a summary and final discussion of the findings and results during the working on the thesis, as well as an outlook.

2 Stormwater on highways

Germany has a total area of about 357,124 km². The non-local road network consists of approx. 231,000 km. Of these, 12,800 km are highways, 39,000 km federal highways, 86,000 km state roads and 91,700 km are regional roads. Within the individual states the transport network is divided as follows [DESTATIS, URL; 04/28/2011]:

Table 1: Streets of the non-local traffic [DESTATIS, URL; 04/28/2011]

State	Streets of the non-local network [km]	Highways [km]
Baden-Wurttemberg	27424	1046
Bavaria	41884	2503
Berlin	246	77
Brandenburg	12391	795
Bremen	119	75
Hamburg	201	81
Hesse	16154	972
Mecklenburg-West Pomerania	9,999	552
Lower Saxony	28,234	1,431
Northrhine-Westphalia	29,552	2,200
Rhineland-Palatinate	18,439	872
Saarland	2,045	240
Saxony	13,565	531
Saxony-Anhalt	10,955	407
Schleswig-Holstein	9,900	533
Thuringia	9,862	498
Germany	**230,969**	**12,813**

According to the WHG, wastewater is defined as “the by domestic, industrial, agricultural or other uses in its properties modified water and at dry weather combined flowing water (sewage) and the collected by precipitation from the range of build-up or paved areas flowing water (rain water)“.

According to DIN 4049-3 (Hydrology – Part 3: Terms for the quantitative hydrology) precipitation is defined as „totality of water particles, liquid or solid, that fall down on the earth's surface"[DIN 4049-3, 1994].

Precipitation can be divided into different forms:

- Drizzle
- Rain
- Snow
- Hail
- Dew
- Rime

The frequency and the average amount of precipitation have a certain effect on the geographic area.

The height of precipitation is given in millimeters. A height of precipitation of 1 mm corresponds to a precipitation amount of 1 l/m^2. Factors such as evaporation, soil infiltration and runoff are not considered.

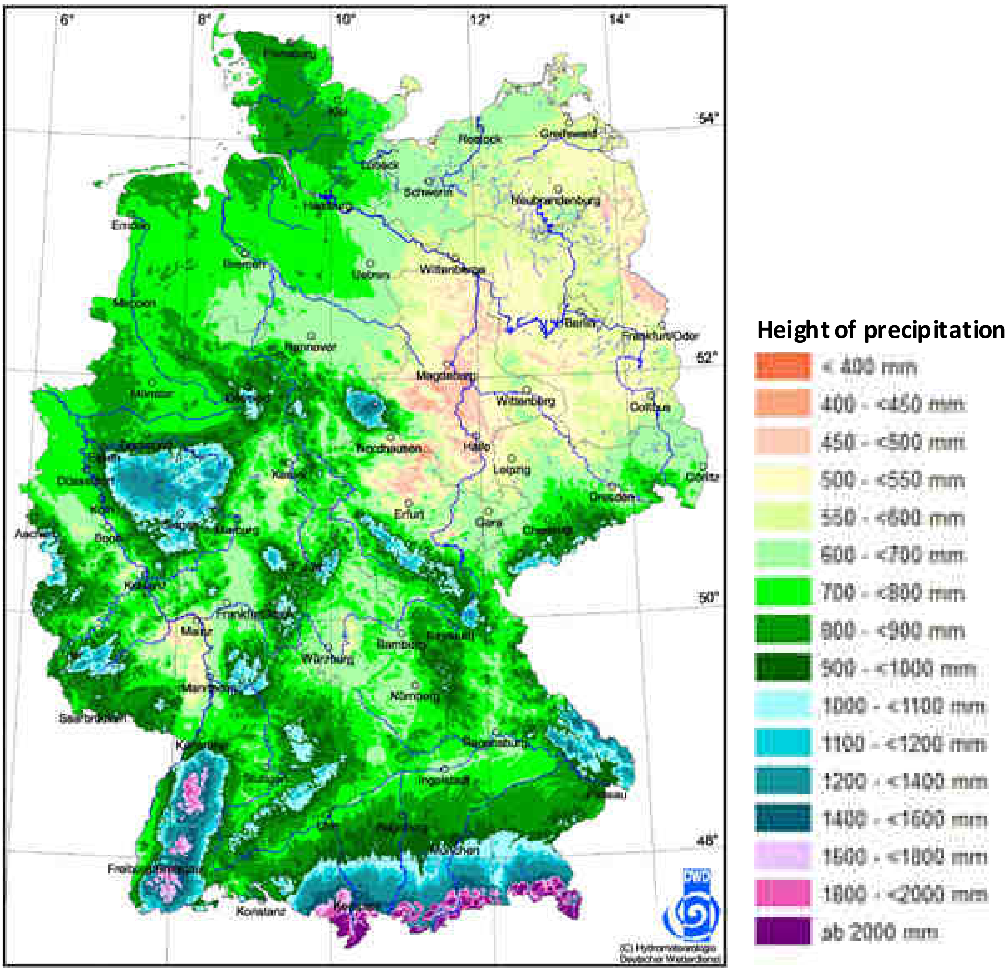

Figure 3 Average annual height of precipitation for the period 1971 – 2000 in mm [wisy, URL; 04/27/2011]

The pollutants of the precipitation runoff strongly depend on local conditions. Especially the land use has an enormous impact on the ingredients and can cause deviations of the average pollutant concentration up to one hundred times [Sommer, H., 2007].

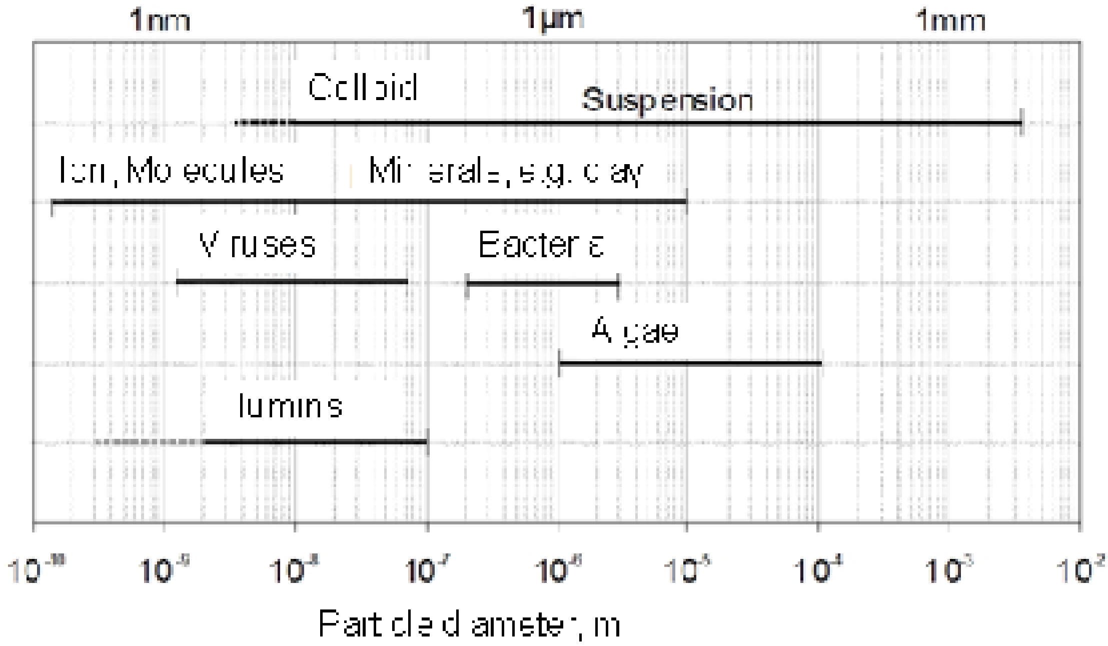

Figure 4: Proportions of substances in water [Wassmann, H., Klein, G., 1994]

Stormwater flows almost entirely off the roadway. It takes substances from the road surface and removes them.

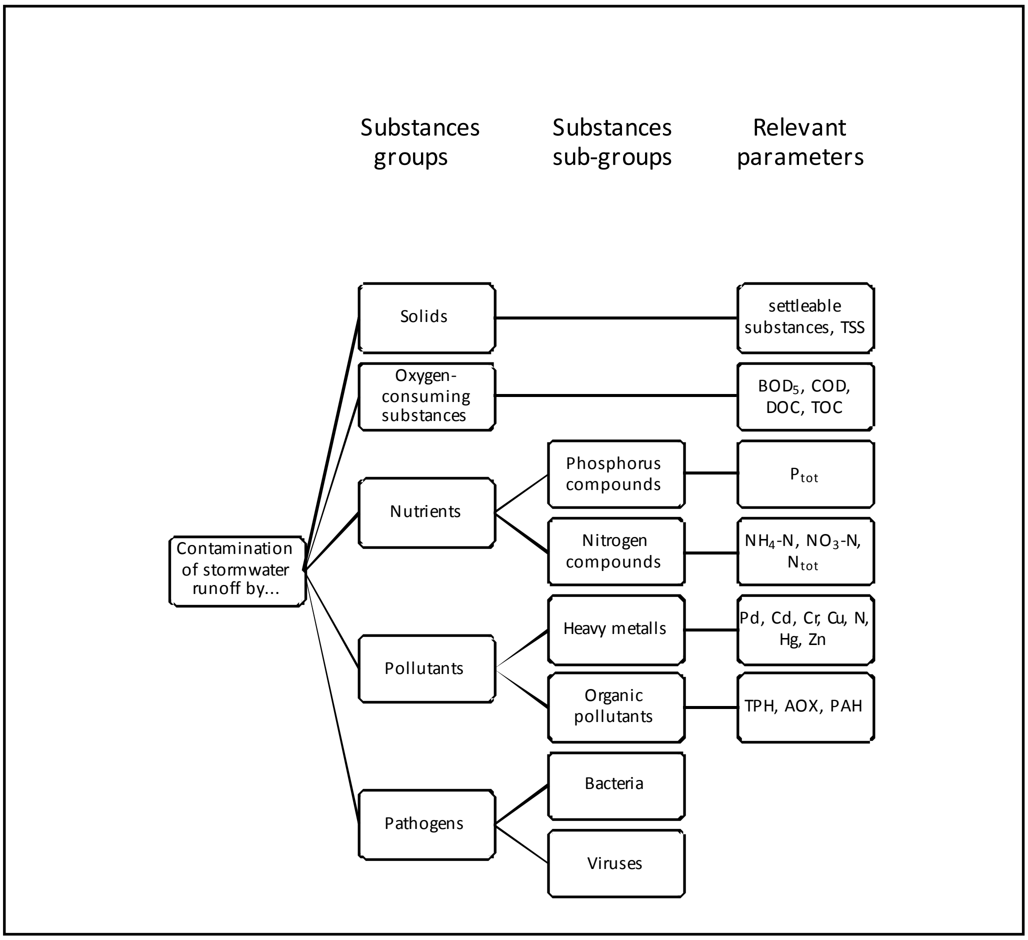

Figure 5 Characterization of pollution in the stormwater runoff by substances groups and selected parameters [Feldhaus, R.; et al., no year]

The sources and materials by motor vehicle traffic are listed in the RiStWag (as shown in Table 2).

Table 2 Sources and matters of the motor vehicle traffic [FGSV, 2002-a]

Source	Matters
Exhaust fumes	Nitrogen oxides (NOx), carbon dioxide (COx), carbon black [carbon, lead, sulfur, chlorine, magnesium, sodium, copper, Zinc], hydrocarbons (PAH), phenols, polychlorinated dibenzodioxins (PCDD) and dibenzofurans (PCDF)
Abrasion of road surfaces	Silicon, calcium, magnesium, chromium, nickel, asphalt
Abrasion of vehicle tires	Hydrocarbons, zinc, sulfur, chlorine, iron, silicon, magnesium, copper, lead, cadmium
Abrasion of brake lining	Hydrocarbon, iron, magnesium, barium, silicon, sulfur, titanium, chromium, vanadium, nickel, copper, zinc
Materials of catalysts	Platinum, rhodium, palladium
Drip losses	Oil, fuels, brake fluid, antifreeze fluid, grease, undercoating protection, detergents and preservatives
Evaporation losses	Hydrocarbons
Corrosion products	Iron, cadmium, zinc, copper

On top of this there are atmospheric preloads, such as heavy metals, PAHs, total petroleum hydrocarbons (TPH), carbon monoxide, sulfur dioxide and oxides of nitrogen and phosphorous. This results in contamination, which can then lead to a change in water quality in surface water or groundwater.

The following solids are in the investigation of effluents with regard to deterioration of ground and surface water of concern [Uhl, M. et al., 2006]:

- total suspended solids (TSS)
- chemical oxygen demand (COD)
- total organic carbon (TOC)
- heavy metals
- Cadmium (Cd)
- Copper (Cu)
- Lead (Pb)
- Zinc (Zn)
- Palladium (Pd)

- Platinum (Pt)
- total petroleum hydrocarbons (TPH)
- polycyclic aromatic hydrocarbons (PAH)
- methyl-tertiary-butyl ether (MTBE)
- Chloride

Table 3 shows the possible range of average and maximum concentration of some pollutant parameters in the stormwater.

Table 3: Range of average and maximum concentration of selected pollutant parameters in stormwater [Lammersen, R., 1997]

Parameter	Average concentration	Maximum concentration
	[mg/l]	[mg/l]
TSS	107 – 339	100 – 999
COD	47 – 115	77 – 996
BOD_5	5.8 – 18.4	4.4 – 260
NO_3-N	0.8 – 7.2	1.2 – 5.2
NO_2-N	0.08 – 0.14	0.16 – 1.6
NH_4-N	0.6 – 2.31	0.3 – 38
PO_4-Ptot	0.3 – 1.8	1.7 – 9.98

In comparison to the end values of a mechanical-biological treatment plant it has been shown that only TSS rates were extremely high and therefore bring a high pollution potential with it. The nutrient and organic values, however, could be considered relatively low [Göttle, A., 1978]; [Heinzmann, B., 1993]. Particularly critical is the intermittent pollution of the water as opposed to continuous exposure to the sewage treatment plant discharge.

It has been shown that heavy metals from roof runoff are dissolved and adsorbed to particles. This depends on the pH and the concentration of dissolved organic matter (DOC). Especially the heavy metals of zinc are more likely to be in soluble form when the pH is low and there is a small fraction of DOC [UBA, 2001]. If heavy metals are bound to particles, it is usually to particles with a size < 0.6 mm and < 1 mm [Göttle, A., 1978].

In addition, especially for small grain sizes of suspended solids, the organic content is high. Coarse components have a particle size > 1 mm, due to their small weight fraction, the low pollution and the simple retention these are of a rather low priority [Göttle, A., 1978].

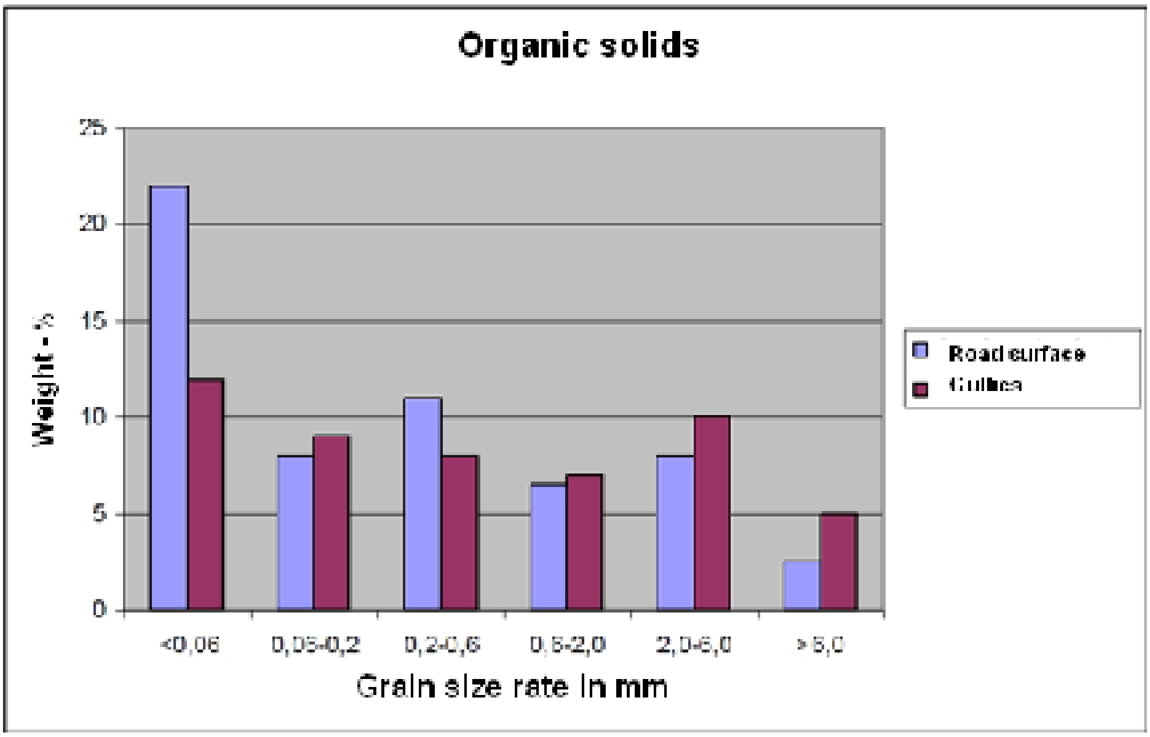

Figure 6: Organic constitutions in stormwater runoffs as a function of particle diameter to Göttle, A. (1987) [Sommer, H., 2007]

By sealing the road surface precipitation flows quickly and without significant delay. This can occur even during heavy rainfall peak flows, which often bring negative impact. It can counteract with structures and procedures for the storage, retention and purification. Table 4 shows established concentrations at measurement programs on streets [Uhl, M. et al., 2006].

Table 4: Overview of freight overall weighted average of measurement programs on road runoffs [Kasting, U., 2003]

Parameter	Number of measurement programs	Unit	Minimum	25 % quartile	Median	75 % quartile	Maximum
TSS	10	[mg/l]	85	125	155	234	564
Chloride	10	[mg/l]	7	84	120	157	357
BOD_5	4	[mg/l]	9		14		18
COD	10	[mg/l]	37	77	99	121	141
NH4-N	10	[mg/l]	0.2	0.5	0.6	0.76	2.31
Ptot	6	[mg/l]	0.25	0.29	0.31	0.34	0.49
Cadmium	10[1)]	[µg/l]	< 1	1.7	3.6	5.5	6.4
Chrome	7[1)]	[µg/l]	< 5	6.3	15	23.3	24.2
Lead[2)]	10	[mg/l]	0.06	0.09	0.18	0.29	0.34
Copper	10	[mg/l]	0.04	0.07	0.11	0.12	0.14
Nickel	6[1)]	[mg/l]	< 0.01		0.026		0.057
Mercury	4[1)]	[µg/l]	< 0.2		0.4		
Zinc	10	[mg/l]	0.25	0.33	0.46	0.52	0.62
PAH (TVO)	7	[µg/l]	0.24	2.08	2.54	2.79	3.39
PAH (EPA)	2	[µg/l]	4.4		5.19		5.98
TPH H18[3)]	8[1)]	[mg/l]	0.005	0.21	1.44	4.75	7.02
pH	4	[-]	7.1		7.35		7.6

1) for some programs, the measurement limit is reached
2) the lead concentration is decreased by the introduction of unleaded gasoline: the average of the measurement program in 1993: 0.08 mg/l
3) in the most recent measurement programs on highways at the BAB A 4 and BAB A 59 a significant decrease in the TPH is reported that there at < 0.1 -0.25 mg/l.

The Table 5 shows that annual ablation rates are expressed in relation to various traffic loads. It is noteworthy that just TSS and COD bring high freight charges with them, even in low-traffic roads.

Table 5: Annual ablation rates and annual average concentrations for surface water for various uses within urban areas [Schäfer, M., 1999]

Traffic area	TSS	COB	Pb	Cu	P_{tot}	N_{tot}	AOX	PAH
Roads DTV < 2.000 Vehicles	1.000 * kg/(ha_u*a)	350 # kg/(ha_u*a)	150 * g/(ha_u*a)	300 # g/(ha_u*a)	4 kg/(ha_u*a)	20 kg/(ha_u*a)	120 mg/(ha_u*a)	6 mg/(ha_u*a)
	333.3 mg/l	116.7 mg/l	0.05 mg/l	0.1 mg/l	1.33 mg/l	6.67 mg/l	0.04 µg/l	0.002 µg/l
Roads DTV 2.000 – 15.000 Vehicles	1350 * kg/(ha_u*a)	350 # kg/(ha_u*a)	200 * g/(ha_u*a)	350 # g/(ha_u*a)	3 kg/(ha_u*a)	20 kg/(ha_u*a)	120 mg/(ha_u*a)	8.5 mg/(ha_u*a)
	450.0 mg/l	116.7 mg/l	0.067 mg/l	0.117 mg/l	1.0 mg/l	6.67 mg/l	0.04 µg/l	0.0028 µg/l
Roads DTV 15.000 – 40.000 Vehicles	850 * kg/(ha_u*a)	350 # kg/(ha_u*a)	400 * g/(ha_u*a)	500 # g/(ha_u*a)	3 kg/(ha_u*a)	20 kg/(ha_u*a)	120 mg/(ha_u*a)	15 mg/(ha_u*a)
	283.3 mg/l	116.7 mg/l	0.133 mg/l	0.167 mg/l	1.0 mg/l	6.67 mg/l	0.4 µg/l	0.005 µg/l
Roads DTV > 40.000 Vehicles	630 * kg/(ha_u*a)	350 # kg/(ha_u*a)	550 * g/(ha_u*a)	400 # g/(ha_u*a)	3 kg/(ha_u*a)	20 kg/(ha_u*a)	120 mg/(ha_u*a)	21 mg/(ha_u*a)
	210.0 mg/l	116.7 mg/l	0.183 mg/l	0.133 mg/l	1.0 mg/l	6.67 mg/l	0.04 µg/l	0.007 µg/l
*: [Xanthopoulps, C., 1996] #: modified by [Schäfer, M., 1999]								

The following table shows that the contamination of the stormwater runoff from streets with DTV = 2,000 – 15,000 [vehicles/d] can be much larger than a car load of 15,000 vehicles/d and clarifies that the matter contamination of the stormwater runoff on streets and highways does not solely depend on the traffic volume [Feldhaus, R.; et al., no year, p. 9 et sqq]

Table 6 Heavy metals concentrations in stormwater runoff from streets and highways, depending on the average daily traffic (DTV) [UBA, 2004]

Heavy metal	Concentration of heavy metals [µg/l]		
	DTV < 2,000 [Vehicles/d]	DTV = 2,000 – 15,0000 [Vehicles/d]	DTV > 15,000 [Vehicles/d]
Zn	56 – 166	202 – 603	236 – 242
Cu	8.8 – 76	17 – 136	109 – 143
Pb	27 – 122	22 – 3611	200 – 203
Cd	1.3 – 1.9	0.7 – 6.4	1.4 – 2
Cr	9.6	8.3 – 24	11

It also plays a role in how far the traffic flow is disrupted by braking- and acceleration processes, which can lead to an increased emission of heavy metals. Possible criteria for assessing such disorders of the traffic can be for example the number of crossings with or without traffic lights, the number of pedestrian crossings and the parking possibilities along a street. Similarly, an increased risk of congestion leads to higher pollutant concentrations.

The increased values in heavy traffic are confirmed by a measurement project in Berlin. Here city highway effluents were examined. The measurement values corresponded to medium to high loads [Sommer, H., et al., 2002].

Table 7: Measured city highway effluents from a measurement project in Berlin [Sommer, H., et al., 2002]

Parameter	Unit	Average	Highway effluents	
			18.05.00	16.06.00
pH	[-]	7.0	7.4	7.4
Conductivity	[µS/cm]	136.6	464	221
E.coli Titer	[KBE/100 ml]		< 100.000	< 2.000
Coli-form. Titer	[KBE/100 ml]		< 200.000	< 200.000
TSS	[mg/l]	210.2	99.5	31.5
TOC	[mg/l]	17.2	28.6	27
DOC	[mg/l]	n/a	20	25.9
COD	[mg/l]	88.1	83	98
Chloride	[mg/l]	30	72	22
AOX	[µg/l]	136.5	40	52
P_{tot}	[mg/l]	0.9	0.37	0.32
PO_4-P	[mg/l]	0.1	0.02	0.02
N_{tot}	[mg/l]	2.8	4	4.1
NO_3-N	[mg/l]	0.8	1.1	1.8
NH_4-N	[mg/l]	1.0	0.7	0.79
TPH	[mg/l]	0.3	0.32	0.33
BOD_5	[mg/l]	15	9.8	20
PAH	[µg/l]	1.9	0.2	1.2
Cd	[µg/l]	5.2	6.08	n.n.
Zn	[µg/l]	687.9	421	357

Cu	[µg/l]	76	78.4	110
Pb	[µg/l]	180.2	40.3	23.3

Another very large collection contains data from 176 reports of measurements in sewers. Here, not only the German sewage was investigated. The data was divided into four categories [Brombach, H; Fuchs, S., 2002]:

- Stormwater runoff in separate sewer system
- Dry weather flow in combined sewer
- Combined wastewater runoff in combined sewer
- Combined sewer overflow water

For the aspect of stormwater runoff on highways only the category „stormwater runoff in separate sewer system" is of relevance.

Table 8: Range of concentrations in the separate sewer system [Brombach, H; Fuchs, S., 2002]

Parameter	Unit	Range	Median	Arithmetic average	Standard deviation	Number
pH	[-]	5.87 – 8.00	7.3	7.14	0.62	18
TSS	[mg/l]	29 – 1535	153	318.8	402.5	51
Conductivity	[µs/cm]	74.4 – 1725	209	363	378.8	28
BOD_5	[mg O2/l]	2.5 – 162.4	11.9	21.4	31.5	32
COD	[mg O2/l]	20 – 351.2	77.1	94.3	67.9	41
NH_4-N	[mg/l]	0.2 – 21.93	0.92	1.81	3.89	30
NO_3-N	[mg/l]	0.2 – 12.83	1.40	2.39	2.77	29
Ptot	[mg/l]	0.08 – 11.58	0.51	1.08	1.99	34
Cd	[µg/l]	0.46 – 30	2.4	4.71	6.83	29
Cr	[µg/l]	3.0 – 178.0	15.5	26.0	40.94	18
Ni	[µg/l]	4.0 – 426.0	29.1	60.7	109.17	14
Pb	[µg/l]	7 – 2408	95	196	368.7	51
Cu	[µg/l]	5.7 – 1143	65	121.8	198.2	44
Zn	[µg/l]	24 – 3563	430	760	809.9	36

Finally, the following points are noted:

First of all it is to determine, that especially the TSS rates bring a high pollution potential with it (compare Table 3). This is also because a large percentage of contaminants such as BOD or COD is bound to solid particles (Table 9).

Table 9 Percentage of contaminants bound to solid particles [Chebbo, G., 1992]

Parameter	**COD**	**BOD**	**N_{tot}**	**Hydrocarbons**	**Lead**
Percentage [%]	83 – 91	77 – 95	48 – 82	82 – 99	79 – 100

In addition, it could be discerned that TSS and COD are not dependent on the traffic volume (compare Table 5). Although most of the other values increase with a higher traffic volume (compare Table 5), but especially the heavy metals, for example, may rise significantly because of interruptions in the traffic flow like traffic lights or pedestrian crossings even during low traffic volume.

3 Legal framework

In this chapter, the relevant guidelines, laws, regulations and rights for road surface drainage will be shown and described in detail. In addition, the essential rules and introductions in the leaflets of the DWA and BWK are listed and described.

3.1 EU law

In the area of environmental law and water rights have to surrender because of the superior EU law, in-depth changes for the individual European member states. By the enlargement of the rights of the European Community with the European Union Treaty of Maastricht and the modification by the Treaty of Lisbon, Community law principle has primacy over national law of member countries. Nevertheless, they must implement law only in those areas (e.g. environmental, climate and energy policy), in which it was authorized by the treaties [National Road Construction NRW, 2011; chapter 3.1.1].

3.1.1 Water Framework Directive (WFD)5

The directive 2000/60/EC [EU-Directive 2000/60/EC, 2000] of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, short Water Framework Directive, demanding quality objectives for water status in the European member states were set. It is foreseen under WFD Article 4 I, that, within 15 years after the directive coming into effect all surface and ground water bodies should be brought in good conditions [Meyerholt, U., 2010, p. 274]. The term “good condition” is defined in Article 2 of the WFD in the concepts of “good ecological” and “good chemical” status for surface water bodies as well as “good quantitatively” and “good chemical” status for groundwater bodies. Artificial and heavily modified bodies of surface water are intended to be developed into a body of water with good ecological potential. Further, there is a ban on the worsening state of the surface waters and groundwater. In addition to the immission targets in accordance with Article 10

[5] Wasserrahmenrichtlinie (WRRL)

WFD discharges are set at an "emissions limitation based on the best available technological" [Sommer, H., 2007, p. 8].

The Water Framework Directive is, like all EU directives, binding as to the results that are to be achieved, but leaves the form and means of implementation to the Member States in. In Germany, their objectives were transposed into national law by the 7th Amendment to the Federal Water Law [National Road Construction NRW, 2011; chapter 3.1.1].

3.1.2 Other relevant EU directives

Other EU directives for the management of stormwater are the Groundwater Directive[6] [EU-Directive 2006/118/EC, 2006], the Directive on Urban Waste Water Treatment[7] [EU-Directive 91/271/EEC, 1991]and the Directive on Dangerous Substances[8] [EU-Directive 2006/11/EC, 2006].

3.2 Law of the Federal Republic of Germany

The most important federal laws and regulations regarding the management of stormwater on highways, in addition to the Federal Water Act[9] and the Waste Water Ordinance[10], are the Federal Soil Protection Act[11] and the Soil Protection Ordinance[12]. However, to date there are no legal targets and requirements for the initiation of precipitation and road runoff into ground and surface waters. [Uhl, M.; et al., 2010, p. 52]

3.2.1 Federal Water Act

The Federal Water Act is the federal law basis of water law in the Federal Republic of Germany. Purpose of the Act is to protect the waters as part of the ecosys-

[6] Grundwasserrichtlinie

[7] Richtlinie über die Behandlung von kommunalem Abwasser

[8] Richtline über gefährliche Stoffe

[9] Wasserhaushaltsgesetz (WHG)

[10] Abwasserverordnung (AbwV)

[11] Bundesbodenschutzgesetz (BBodSchG)

[12] Bodenschutzverordnung (BBodSchV)

tem, in terms of livelihood of the people, as habitat for animals and plants as well as usable Good by a sustainable water management [WHG, 2009, § 1].

According to WHG § 8 the use of water requires the permission of the authority. Comparing the facts for use in WHG § 9 it is clear that the road runoff in the direct discharge into a water body also is one of the intended use. According to WHG §9 the addition and discharge of substances into waters, the withdrawal and transport to the surface and the discharge of groundwater play a major role.

For the discharge of stormwater into groundwater through harmless percolation, it needs to WHG § 46 para 2 no water Act permit, if it is determined in an ordinance. Such an ordinance has not yet been enacted, but WHG § 46 para 3 declares that state regulation exclude other cases of licensing requirements [National Road Construction NRW, 2011; chapter 3.1.1]. Some states, inter alia Northrhine-Westphalia, have exercised this right and adopted their own ordinances.

In accordance with WHG § 54 para 1 No. 2 discharging water (stormwater) that is collected from the range of developed or paved area is defined as waste water. The incidental stormwater to WHG § 55 para 2 will primarily percolate locally, be sprinkled or be discharged directly through a sewer system into a water body without being mixed with wastewater. This shows that the new Federal Water Act clearly prefers the separation system over a combined sewer system.

Since the amendment of the WHG 1996 the “generally acknowledged rules of technology” no longer serve as the technological requirement level, but according to WHG § 57 para 1 the “prior art” [National Road Construction NRW, 2011; chapter 3.3.1]. A permit of discharge of sewage may only be granted if the quantity and harmfulness of the waste water is kept as low as possible in compliance with the respective procedures under consideration by the prior art, and if the discharge is compatible with the requirements to the properties of water [WHG, 2009; § 57 (1) 1 and 2].

3.2.2 Waste Water Ordinance

The Waste Water Ordinance of 17 June 2004 [AbwV, 2004] are the minimum requirements needed in the WHG (prior art) the discharge of wastewater into waters in the municipal wastewater treatment determined [Sommer, H., 2007, p. 11]. The regulation contains a total of 57 attachments with specific regulations for domestic sewage and various industrial sectors [AbwV, 2004]. In principle, the limits listed apply to all wastewater treatment plants, thus also for stormwater treatment facilities. However, no “Annex stormwater” is attached to the regulation, in so far concrete conclusions about the combined and stormwater treatment are missing [Sommer, H., 2007, S. 11]. For several years the development of an appropriate attachment has been in progress, but currently the process is resting [Sieker, H., 2010, slide 16].

3.2.3 Wastewater Charges Act13

The Wastewater Charges Act [AbwAG, 2005] regulates the obligation to pay fines for the discharge of wastewater into waters. According to AbwAG § 2 para 1 dirt water and stormwater in the area of developed or paved areas are labeled wastewater, this serves the purpose of the Wastewater Charges Act. In this case it must be noted that discharging stormwater into water bodies is only taxable if made as an indirect discharge via a public sewer. In such case, the Federal Water Act does not apply [Meyerholt, U., 2010, p. 286].

3.2.4 Federal Soil Protection Act

The Federal Soil Protection Act [BBodSchG, 1998] aims the security and to restoration of the functions of the soil sustainably in terms of its performance. For this purpose harmful soil changes are to fend off, soil and contaminated sites, thereby water pollution is caused, are to rehabilitate and to take precautions against adverse impacts on the soil [BBodSchG, 1998, § 1]. The BBodSchG protects the soil above and below the groundwater table and to the ground belonging soil solution that belongs to the ground- and percolation water); the groundwater itself is protected from the WHG.

Because the percolation and discharge measures of traffic areas may influence the soil in terms of the groundwater and sediment balance, the road surface discharge is observed even in the Federal Soil Protection Act [Sommer, H., 2007, p. 13].

[13] Abwasserabgabengesetz (AbwAG)

3.2.5 Soil Protection Ordinance

The Federal Soil Protection and Contaminated Sites Ordinance [BBodSchV, 1999] specifies and supplies the Federal Soil Protection Act with provisions for implementation, with requirements for preventive soil protection as well as requirements for the rehabilitation of contaminated sites and harmful soil changes. For the field of preventive soil protection the BBodSchV also includes trigger values to assess the effect of soil-groundwater path [Sommer, H., 2007, p. 13]. With the discharge of stormwater into the groundwater through percolation in the soil, trigger values from BBodSchV are often applied. It is therefore likely that after the draft “annex stormwater” of the AbwAG of 2009, stormwater might be percolated only when the trigger values observed by the surface runoff or the discharge values of a treatment plant [Uhl, M.; et al., 2010, p. 52].

This clearly shows that the BBodSchV is important, also in terms of percolation of road surface water, e.g. is the percolation of surface water on the road batter and through troughs, is important.

3.2.6 Other legal regulations

In addition to these legal regulations the Federal Nature Conservation Act[14] [BNatSchG, 2009] and the Town and Country Planning Code[15] [BauGB, 2004] can be relevant for the road drainage.

3.3 Law in the federal states

The legal situation in the individual states is very diverse. Some states refer only to the laws and regulations of the federal government when relating to the subject/ dealing with the subject of management of stormwater on highways.

[14] Bundesnaturschutzgesetz (BNatSchG)

[15] Baugesetzbuch (BauGB)

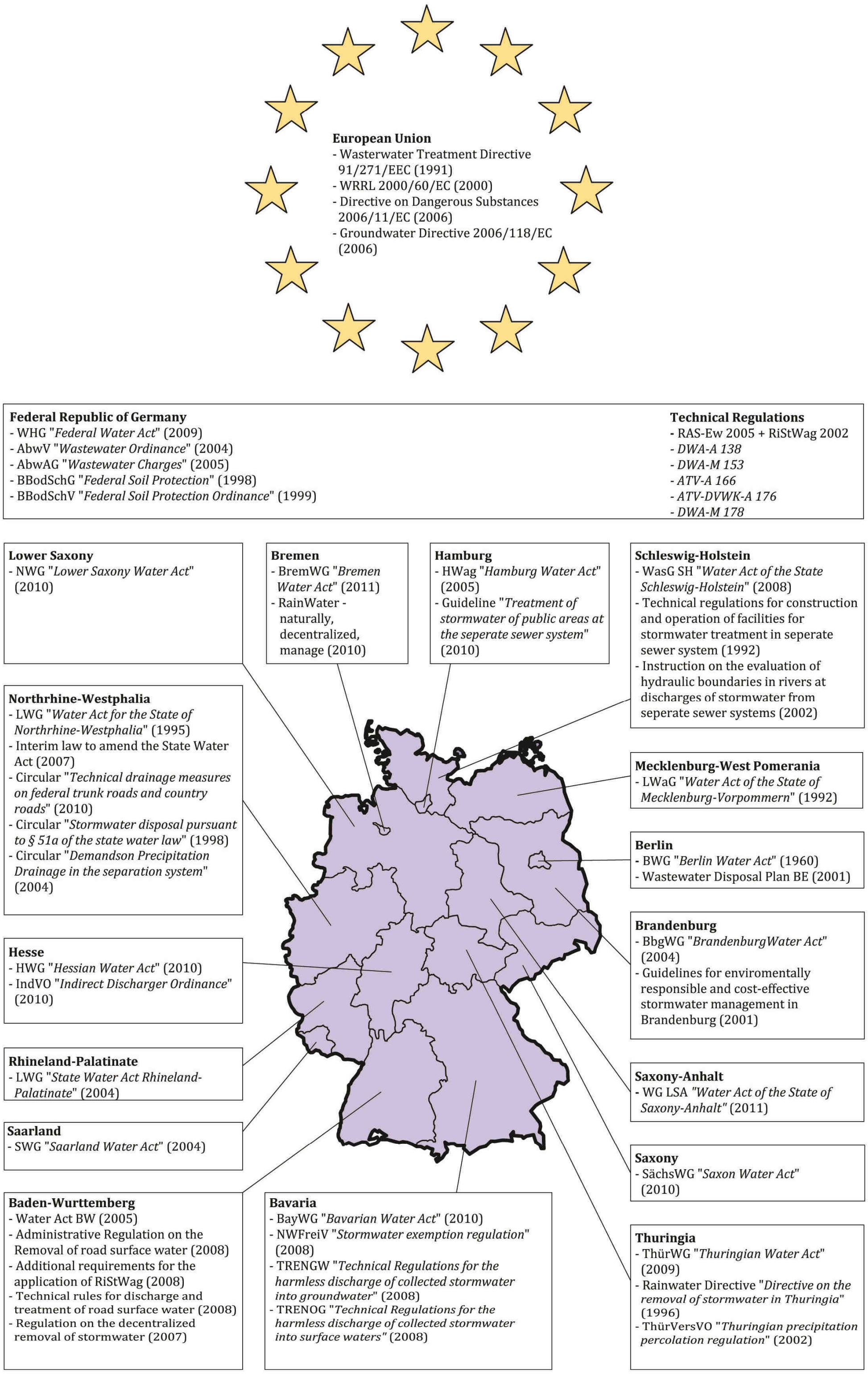

Figure 7 Overview of the legal situation in the federal states

Baden-Wurttemberg

In order to achieve a desired harmless percolation [WG Baden-Wurttemberg, 2005; § 45b (2) No. 1], the Ministry of Environment has issued detailed regulations in a "Regulation on the Decentralized Removal of Stormwater" [UMBW, 2007]. Thus stormwater might be percolated without a license, or be discharged into surface waters, when it comes from local roads outside built-up sites and not from parking spaces or more than two-lane roads [UMBW, 2007; § 2 (1) No. 3]. A harmless removal of surface water should be achieved with a surface or in troughs guided percolation, via a minimum of 30 cm thick vegetated soil zone. In addition, the stormwater will be kept back before the discharge into a surface water (stormwater storage tank) [UMBW, 2007; § 2 (2)]. In water protection zones of zone I and II and in areas with harmful soil change stormwater may not be percolated without permission.

The systems for decentralized stormwater treatment are to be designed, maintained and operated according to the accepted rules of technology [UMBW, 2007; § 3 (3)].

These fundamental requirements for wastewater systems according to the WHG is supplemented in Baden-Wurttemberg on the basis of WG § 43 (2) No. 3 for more "Technical rules for discharge and treatment of road surface water" and with the "Administrative Regulation on the Removal of road surface water" established bindingly. As an annex in this administrative regulation "Additional requirements for the application of RiStWag" are taken. With the additional technical rules a compilation of technical foundations is sought on the basis of scientific findings and advice on the legal foundations are offered. If possible, economic solutions for the treatment of road surface water under the observance of legal requirements should be achieved.

In the "Additional requirements for the application of RiStWag" different rules to the RiStWag are listed. They are adapted to the situation in Baden-Wurttemberg. These adjustments are made based on previous experiences in the country about the potential hazards of the traffic and the selection and design of treatment systems for the road surface water [IMBW a. UMBW, 2002].

In the “Administrative Regulation on the Removal of road surface water“ the principles and objectives are listed, which should be applied at new constructions of roads and changes of no minor significance [IMBW a. UMBW, 2008-a]. Road surface is therefore to treat, in principle, prior to the discharge into a water body.

Bavaria

The Bavarian Water Act [BayWG, 2010] was redesigned with the amendment of the WHG and is valid since 01 March 2010 for two years. Here are some additional rules and variations to the paragraphs of the WHG.

In Bavaria further provisions for the treatment of wastewater of streets are made in the Stormwater exemption regulation [NWFreiV, 2008] and in the “Technical Regulations for the harmless discharge of collected stormwater into surface waters” [TRENOG, 2008].

Following the NWFreiV collected stormwater from country and local roads with more than two lanes, as well as legal plan approval roads does not be percolated without permission [NWFreiV, 2008; § 2 No. 2 and 3]. In addition the TRENOG mentions country and local roads with higher traffic volume (5,000 vehicles/day) [TRENOG, 2008; numeral 3.2]. Moreover more precise conditions are mentioned, under which no discharges into watercourses or still waters are allowed. If a discharge cannot be avoided despite these conditions, then stormwater of traffic areas with low traffic (up to 300 vehicles/d) can only be discharged after purification (50 m long ditch, sand or soil filters, settling tanks, etc.) [TRENOG, 2008; numeral 4.6]. In the case of traffic areas with a daily traffic volume of 300 – 5,000 vehicles/d additional conditions to those listed under 4.6 have to be met [TRENOG, 2008; numeral 4.7].

Berlin

In addition to the federal regulations and the technical regulations of the DWA, the sewage disposal scheme Berlin is concerned with the discharge of road surface water. The scheme declared that a direct discharge of road surface water into waters only make place with a detection according to the ATV recommendations, including the water resistance and at least the installation of a grit chamber (for the grain size of ≥ 0.5 mm, quartz sand or v_{sink}= 7.2 cm/s, t_0 ≥ 1.0 m, v ≥ 0.3 m/s) with scumboard and possibly an oil collection chamber. An indirect discharge via a third discharge into a water body has the same requirements [Berlin environment, 2001]. The conditions for percolation of stormwater into the areas outside of the drinking water protection zone I and II are shown in Table 10.

Table 10 Conditions for percolation of stormwater into the areas outside of the drinking water protection zone I and II (abridgement) [Berlin environment, 2001]

		Type of percolation system							
		width surface percolation with top soil passage		**decentralized trough and trough-ditch percolation**		**semi-central and central seepage reservoir (loaded inter-centered)**		**Shaft-, pipe and ditch-percolation without topsoil passage**	
		(≥ 30 cm top soil)		≥ 30 cm top soil with A_{red}:A_S < 15:1)		≥ 30 cm top soil with A_{red}:A_S < 15:1)			
		outside WPZ	WPZ III (A,B)	outside WPZ	WPZ III (A,B)	outside WPZ	WPZ III (A,B)	outside WPZ	WPZ III (A,B)
7	**Local street, passable residential path, pedestrian street (without buses and cargo traffic, DTV ≤ 500 vehicles/d#, construction class V, VI)**	1	1	1	1	1	1	0	0
8	**Residential collector street, pedestrian street with cargo traffic, DTV 500 to ≤ 2,000 vehicles/d#, construction class III, IV**	1	1	1	2	1	2	0	0
9	**Main road, industrial road, street in the industrial area, DTV 2,000 to ≤ 15,000 vehicles/d#, construction class II, III**	1	2	2	2	2	2	0	0
10	**Expressway, industrial collector road, DTV over 15,000 vehicles/d#, construction class SV, I, II**	2	0	2	0	2	0	0	0

Brandenburg

Legal basis in the state of Brandenburg for dealing with stormwater results from the Brandenburgisches Wassergesetz (BbgWg; Brandenburg Water Act). According to § 54 (4) stormwater is to seep, as far as contamination of ground water is not expected and other concerns do not oppose [BbgWg, 2004]. There also is a guide to environmentally sound and cost-effective stormwater management in Brandenburg for the local authority districts. Here, various treatment methods for stormwater are presented. The design and operation, and their applications follow the applicable technical regulations. With regard to the percolation roads with a DTV of 2,000 vehicles are judged to be tolerable. In Brandenburg, surface percolation, trough percolation and a seepage reservoir are generally allowed. A ditch-pipe percolation only in exceptional cases and a shaft percolation are not allowed. Roads with traffic more traffic value than 15,000 are in the transition zone between tolerable and not tolerable. Only the surface percolation is generally permissible. Ditch-pipe percolation and shaft percolation are generally not allowed [MLUR Brandenburg, 2001]; [Merten, Oliver Dr., 2011; e-mail].

Bremen

The Bremen Water Act [BremWG, 2011] is the only regulation for treatment of road surface runoff in this state. However, the Senator for Environment, Construction, Traffic and Europe published the information booklet “RainWater – naturally, decentralized, manage” [SUBVE, 2010]. After this, polluted runoff from highly frequented traffic areas are primarily percolated through the vegetated topsoil. New construction measures have to make use of this method. At a higher pollution rate the topsoil should have a thickness of 30 cm. Furthermore, the soil should not be impacted by contaminated sites or adverse changes in the soil [SUBVE, 2010; p. 14].

Prior to a discharge of polluted traffic runoffs into waters, these should be treated by stormwater sedimentation tanks with upstream settlement tank and scumboard. Some systems are equipped with a downstream plant bed or soil filter level [SUBVE, 2010; p. 16].

Hamburg

In addition to the relevant Hamburg Water Act [HWag, 2005] the city state of Hamburg has published a guideline for the treatment of stormwater of public areas at the separate sewer system [BSU, 2010]. It also deals with the treatment of road surface water. Furthermore, the Ministry of Urban Development and Environment of the City of Hamburg has issued a draft directive, which makes statements to the discharge of surface water from road surfaces. Yet this applies mostly to local traffic areas.

In the above mentioned guideline stormwater that accumulates in public areas is divided according to its source and load into different load classes. It applies a mixing prohibition of different polluted stormwater and an advantage of decentralized treatment methods on site. The load classification is divided into slightly, medium and heavily polluted. Surface water with an average daily traffic volume of < 15,000 vehicles/d is medium polluted. This is to treat generally at least elementary mechanically as well as pre-connected light liquid separator. Surface water from roads with DTV of > 15,000 vehicles/d is generally classified as heavily polluted and conditioned in addition to the basically mechanical treatment a further cleaning stage in the form of filtration systems [BSU, 2010; numeral 1,3 and 4].

Hesse

The Hessian Water Act [HWG, 2010] applies to § 1 (1) for the water derived from precipitation, whether it is caught and collected or runs off wild. It is further stated that road ditches are excluded as part of the streets, if they are of secondary importance to water management [HWG, 2010; § 1 (2)].

Moreover, Hesse has no other specific regulations on the handling of road surface runoff. The “Regulation on the discharge or the inserting of wastewater containing hazard substances in public water systems” [IndVO, 2010] however is a special case. According to § 4 systems, which produce mineral oil contain waste water operatively, will be reviewed every 2.5 years by an expert. In Thuringia, these guidelines also apply.

Mecklenburg-West Pomerania

In Mecklenburg West Pomerania, there are no national regulations. There are the RAS-Ew, the RiStWag and the technical regulations of the DWA and the DIN [Gürcke, F., 2011; e-mail].

Lower Saxony

For Lower Saxony no data is available.

Northrhine-Westphalia

In addition to the [LWG NRW, 1995] that was amended on 06/26/1995, Northrhine-Westphalia adopted different technical rules for the drainage of stormwater in the form of administrative rules have been adopted. This includes the circular "Stormwater disposal pursuant to § 51a of the state water law" [MUNLV NRW, 1998], the circular "Demands on Precipitation Drainage in the Separation System" [MUNLV NRW, 2004] and the circular "[MBV-NRW a. MUNLV-NRW, 2010]. As an administrative regulation such technical rules obtain legal obligation in NRW. Furthermore the "Planning Guide Road Drainage and Water Protection" [National Road Construction NRW, 2011], developed by the National Road Construction NRW, is an internal working tool regarding the treatment of road surface water. Moreover, the provisions of the RAS-EW and the RiStWag are used.

According to the § 51a LWG NRW and the circular "Stormwater disposal pursuant to § 51a of the state water law" a statutory basis obligation for percolation or damping on-side or local discharge of stormwater into a water body was introduced. Here, in principle, the local discharge occurs in accordance with the § 51a of the LWG NRW in the separation system [MUNLV NRW, 1998; numeral 1]. Furthermore, the non-targeted area percolation of surface water through the road batter or the adjacent area with topsoil zone is permit exemption [National Road Construction NRW, 2011; numeral 3.1.3.3.3.].

A percolation of road runoff is permitted only when there is a sufficient permeability of the soil (k_f-value between $1*10^{-3}$ and $5*10^{-6}$), a depth to groundwater of at least 1 m and soils are not preloaded due to old landfills and contaminated sites. In principle, water and water sections with high ecological-functional significance or high protection needs should be kept free of introductions. For percolation and discharges at water protection areas the regulation of the RiStWag should be applied [MUNLV NRW, 1998; numeral 11].

According to the circulars “Stormwater disposal pursuant to § 51a of the state water law” and “Demands on Precipitation Drainage in the separation system” the stormwater is classified in the categories of unloaded, weakly loaded and heavily loaded after its treatment. Surface runoff from sidewalks, bike lanes and living paths without substance deposition by the adjacent streets are considered uncontaminated stormwater and require no treatment measures. Weak loaded surface runoff from non-urban streets with a traffic volume of about 2,000 vehicles/d can be percolated through the topsoil zone or discharged into surface waters by an upstream treatment. Discharges from non-urban streets with a traffic volume of 15,000 vehicles/d, highways and federal roads are regarded as highly loaded runoffs and generally require to the degree of stress appropriate treatment. A percolation of this runoff is allowed only on non-urban main roads and highways as well as with an upstream installation of systems to minimize the pollutant entry [Uhl, M. et al., 2006; p. 18]; [MUNLV NRW, 1998; numeral 12] and [MUNLV NRW, 2004; numeral 2.4].

Rhineland Palatinate

In Rhineland-Palatinate no further regulations for the treatment of stormwater on roads exist besides the State Water Act Rhineland Palatinate [LWG - Rhineland-Palatinate, 2004].

The scope of state water law exclude road ditches, where they form part of public roads and are not receiving water of the estate of other owners. A harmless discharge of stormwater on public roads within and outside the enclosed site in accordance with § 36 (4) given. Roadways and parking space on public roads with more than two lanes are an exception to this. Special attention is also directed to the replaced areas and narrow water protective zones and mineral spring protection areas, nature reserves, springs and their immediate environment and waters or river sections with water quality class. Here a harmless discharge is only possible if the discharge points are located outside these areas.

Saarland

After the Saarland Water Act [SWG, 2004] stormwater should be utilized, percolate, sprinkled whenever on site, or discharged into surface waters, if this does not lead to adverse effects for the common good and the statues of a municipal waste water ordinance is not reserved. Moreover the necessary facilities should comply with the generally recognized rules of technology [SWG, 2004; § 49a (1)]. Under § 49a (4), the above-mentioned obligations do not apply for stormwater, which is mixed with public wastewater in the present sewerage and supplied to the wastewater treatment plant, if the desired success is the effort required from a technical and economic point of view of proportion.

Specific regulations on the management of runoff of road surfaces are not taken.

Saxony

In Saxony, there are no national regulations. There are the RAS-Ew, the RiStWag and the technical regulations of the DWA and the DIN [Oertel, Annett, 2011; e-mail].

Saxony-Anhalt

In Saxony-Anhalt only technical information including instructions for planning and design exists besides the RAS-Ew and the RiStWag. This involves the discharge, retention and treatment of stormwater with open, favoring the percolation systems.

Schleswig-Holstein

The Ministry of Environment of Schleswig-Holstein and the data sheet 2 [MLUR SH, 2002] issued technical regulations for the construction and operation of facilities for stormwater treatment in separate sewer systems [MLUR SH, 1992]. These methods are used alongside with the Water Act of the State Schleswig-Holstein [LWG SH, 2008]. The former specifies the requirements for the discharge of stormwater from separate sewer systems into rivers, not only to limit the harm but also the amount, according to the state of the art.

The technical regulations of the Schleswig-Holstein Ministry of the Environment are intended to protect the waters from preventable impairments caused by stormwater discharges from the separate sewer system. After that, stormwater is basically treated before the discharge. For the treatment of stormwater storage tanks, light liquid separators, stormwater sedimentation tanks, vortex separators, vegetation passages, soil filters and bon systems are possible methods [MLUR SH, 1992; numeral 1 and 2.4].

The draining stormwater from paved surfaces is classified on the source area in slightly, normally or highly polluted based on the technical regulations. Thereby highly polluted discharges should be discharged separated if possible. Surface runoffs from major roads are only classified as normally polluted and should be treated at least in a stormwater sedimentation tank or through a trough drainage. For discharges into the groundwater, stormwater should be percolated through the vegetated topsoil [MLUR SH, 1992; numeral 3.2, 5.2, 5.4 and 8].

Thuringia

In addition to the RAS-Ew and the RiStWag the state of Thuringia has also adopted the Thurinigan Rainwater Directive [TLUG, 1996]. It specifies that stormwater from roads with an average daily traffic volume (DTV) of less than 2,000 vehicles with sufficiently powerful rivers and favorable conditions can be discharged without treatment. The excessively contaminated stormwater from other derivations in the separation system requires the mechanical treatment in a stormwater sedimentation tank. Further details were not disclosed. Reference is made to the RAS-Ew.

The directive of 1996 is currently being revised, but is not yet valid. The directive strongly refers to the DWA-M 153 [ATV-DVWK-M 153E, 2000].

3.4 Regulations and standards

Technical regulations and standards are recommendations and technical proposals from professional bodies or associations that present a particular solution to maintain with any law, regulation or a technical workflow. But they are not legal norms and do not have necessarily the value of a law or ordinance. Technical regulations can be legally binding unless it is clearly in the regulations referred to them [Sommer, H., 2007, p. 21].

3.4.1 EN / DIN standards

DIN standards are the result of national, European or international standardization work, which is implemented by the respective committees of the German Institute for Standardization[16] and the European Committee for Standardization (CEN). At the international level, this is the International Standardization Organization (ISO).

The most important standard for the discharge of road surface water is the DIN EN 752 “Drain and sewer systems outside buildings” [DIN EN 752, 2008]. The scope of DIN EN 752 applies to the sanitation and public sewer to the sewage treatment plant. Further, the DIN EN 858 “Separator systems for light liquids (e.g. oil and petrol)” [DIN EN 858, 2002] needs to be mentioned.

3.4.2 RAS-Regulations

With the RAS-Ew (Directive for the construction of roads – Part: Drainage[17]) and the RiStWag (Guidelines for structural measures on roads in water catchment areas[18]) the Research Society for Road and Transport for road drainage will issue two very important technical codes. It should be noted that they are significant for the field of road drainage, although in special cases they are not the conclusive basis. The local water authority is eligible for participation and permission procedures certainly higher demands on water protection. The technical evaluation follows these water management principles that are defined in relevant regulations (e.g. Data Sheet M 153 and A 138).

3.4.2.1 RAS-Ew

According to the RAS-Ew basically a surface percolation of road surface water on the batter or on the lawn dump is desirable. This requires large unpaved areas to be filled with water-permeable soil in order to absorb the harmless road surface water. The top soil of the vegetated soil area should have a thickness of about 20 cm; in road batters steeper than 1:2 have a layer thickness of 10 cm. To ensure permeability and cleaning effect, a k_f-value of soils of 10 – 3 m/s to 10 – 5 m/s is

[16] Deutsches Institut für Normung (DIN)

[17] Richtlinie für die Anlage von Straßen – Teil: Entwässerung (RAS-Ew)

[18] Richtlinien für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten (RiStWag)

required. A closed, underground system s preferred to an open, above- ground discharge system. Furthermore, the discharge system might be as natural as possible [RAS-Ew, 2005, Numeral 1.2.3, 1.3.2, 7.2.1].

If percolation through the batter or lawn dump is not possible due to geological, hydrological, ecological or structural reason, then a collected dissipation and percolation in an appropriate place via percolation system is preferable. For this percolation troughs and trenches, seepage reservoirs and retention soil filters are possible methods. These systems should be preceded by sedimentation tanks in form of settling tanks, stormwater sedimentation tanks and separator of light liquids [RAS-Ew, 2005, Numeral 1.2.3, 7.2].

According to RAS-Ew surface water from roads with less than 2,000 DTV can be discharged into open waters or percolated properly without treatment. On the other hand, surface water from roads with 2,000 or more DTV should be supplied to a treatment. Treatment also includes the proper percolation through the vegetated soil area [RAS-Ew, 2005, Numeral 7.1]. The need for treatment of road surface water is therefore under the RAS-Ew a function of frequenting of the road. The RAS-Ew does not deal with which treatments for non-percolation critical discharge should be used under which conditions. Insofar the relevant rules of the water management (e.g. DWA-M 153 and DWA-A 138) supplement the RAS-Ew.

3.4.2.2 RiStWag

The “Guidelines for structural measures on roads in water catchment areas” [RiStWag, 2002] applies to planned, established and expanded roads in water protection areas. Moreover, it also applies to areas that serve the public catchment, but for which no protection area have been established. The RiStWag distincts between percolation systems, sedimentation systems and separators for the treatment of road surface water in protected areas. The listed structural protection measures for water protection areas depend on the protective effect of groundwater cover, the vulnerability of each protection zone I, II or III and the amount of traffic in DTV.

Table 11 Classification of discharge measures in the protection zone III [RiStWag, 2002]

DTV	**zone III or III A** Protective effect of groundwater cover*			**zone III B** Protective effect of groundwater cover*		
Vehicles	**high**	**medium**	**low**	**high**	**medium**	**low**
< 2 000	level 1	level 2	level 2	level 1	level 1	level 2
2 000 to 15 000	level 1	level 2	level 3	level 1	level 1	level 3
> 15 000	level 2	level 3	level 4	level 1	level 2	level 3
* see [RiStWag, 2002; Table 2]						

In protection zone III, as illustrated in Table 11, protection levels are defined depending on the traffic load in DTV and the protective effect of the groundwater cover. Road surface water at level 1 should be percolated largely by the vegetated topsoil, ditches or troughs or percolation tanks. The latter are permitted only in level 2 with upstream settling systems. In contrast, road surface water of level 3 and 4 should be discharged out of the protection area in dense pipes or in sealed troughs, ditches or channels. High-edged curbs and road gullies need to be constructed for the collection of the water. Other seals of the batter should be provided at level 4 [RiStWag, 2002, numeral 6.2.6].

In the protection zone II the percolation of road surface water is generally not allowed. It should be collected and discharged out of the zone II in dense pipes and in gutters with permanently sealed fugues [RiStWag, 2002, numeral 6.2.6].

Road surface water in the protection zone I, II or III should not be discharged into surface water. For compelling reasons these can still be discharged if this does not adversely affect the waters. For roads with traffic load of less than 2,000 vehicles / day does not have to be a treatment. Road surface water from roads with a DTV of 2,000 to 15,000 can be discharged without prior treatment with coordination of the water management permission authority [RiStWag, 2002, numeral 6.4.1].

3.4.3 DWA Advisory leaflets19 / Work sheets20

The German Association for Water Management, Wastewater and Waste[21] develops as a technical and scientific professional association with a comprehensive regulatory framework of different advisory leaflets, as well as worksheets for the urban water management. These are generally accepted as a basis for planning, construction and operation of systems of the water and wastewater management. Following the relevant advisory leaflets and worksheets for the treatment of road surface water are listed.

3.4.3.1 DWA-A 138

The DWA Worksheet A 138 [DWA-A 138, 2005] provides information about "planning, construction and operation of facilities for the percolation of precipitation water".

The following percolation methods will be discussed in the DWA-A 138:

- area percolation
- trough percolation
- trough-trench percolation
- trench and pipe-trench percolation
- shaft percolation
- tank percolation
- trough-trench systems

According to Table 1 of the DWA-A 138 percolations or road surface runoffs through above-ground percolation systems are to be preferred. Only in exceptional cases, the subterranean percolation of lightly loaded traffic is permitted. In order for traffic area runoffs to be percolated through trenches and shafts, in the past few years several decentralized stormwater treatment measures were developed.

[19] DWA Merkblatt (M)

[20] DWA Arbeitsblatt (A)

[21] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (DWA)

These can also be used as a precursor before percolation systems [KA No. 4, 2011].

The design of percolation systems in the sense of the DWA-A 138 is based on the DWA-A 117 with a simple method using a continuity equation [KA No. 5, 2011]. Thus, the same design principle is applied, which is also used for stormwater holding tanks [Sommer, H., 2007; p. 25].

3.4.3.2 DWA-M 153

In the DWA Advisory Leaflet M 153 "Recommendations for action for handling with stormwater"[ATV-DVWK-M 153E, 2000] planning assistances for the selection of measures for stormwater treatment are presented. The scope extends beyond simple water conditions, separation systems, modified drainage systems and road drainage. Here, the runoff pollution, the local water situation and the effectiveness of treatments are evaluated based on a scoring system [Uhl, M.; Grotehusmann, D., no year].

In the DWA-M 153 measures for stormwater treatment the percolation through the soil passage, filtration systems, sedimentation systems and chemical-physical processes are listed. The restriction on individual types of procedures should be regarded as a disadvantage, because the schema cannot be transferred for newer methods of treatment [Sommer, H., 2007; p. 26].

Table 12 Evaluation points of stormwater runoff, depending on the area of origin according to Table 3 ATV-DVWK M 153 [Uhl, M.; Grotehusmann, D., no year; p. 5]

<table>
<tr><th colspan="4">Load from the area</th></tr>
<tr><th>Surface contamination</th><th>Examples</th><th>Type</th><th>Points</th></tr>
<tr><td rowspan="5">low</td><td>green roofs</td><td>F1</td><td>5</td></tr>
<tr><td>roofs* and terrace surfaces in residential and comparable commercial areas</td><td>F2</td><td>8</td></tr>
<tr><td>bike lanes and sidewalks outside the spray and spray plume area of roads (distance > 3 m)</td><td rowspan="3">F3</td><td rowspan="3">12</td></tr>
<tr><td>yard and car parking areas without frequent change of vehicles in residential and comparable commercial areas</td></tr>
<tr><td>little-used traffic areas (≤ 300 vehicles/d) in residential and comparable commercial areas</td></tr>
<tr><td rowspan="3">medium</td><td>roads with 300 – 5,000 vehicles/d</td><td>F4</td><td>19</td></tr>
<tr><td>yard and car parking areas without frequent change of vehicles in mixed, commercial and industrial areas**</td><td rowspan="2">F5</td><td rowspan="2">27</td></tr>
<tr><td>roads with 5,000 – 15,000 vehicles/d</td></tr>
<tr><td rowspan="5">high</td><td>car parking with frequent change of vehicles</td><td rowspan="3">F6</td><td rowspan="3">35</td></tr>
<tr><td>roads and places with high pollution</td></tr>
<tr><td>roads > 15,000 vehicles/d</td></tr>
<tr><td>busy truck access roads to commercial, industrial or similar areas</td><td rowspan="2">F7</td><td rowspan="2">***
45</td></tr>
<tr><td>truck parking spaces</td></tr>
<tr><td colspan="4">* copper-, zinc- or plump-covered roof surfaces: special regulations
** handling areas in commercial and industrial areas are to be determined in each individual case
*** percolation only allowed with control option after the cleaning</td></tr>
</table>

3.4.3.3 DWA-A 166

The Worksheet “Buildings for the central stormwater treatment and retention - Engineering design and equipment” [ATV-A 166, 1999] contains guidance for the construction of stormwater tanks for construction, equipment, technical, operational and economic aspects. Here, the term “stormwater tank” includes buildings of the central stormwater treatment and retention of stormwater in the combined and separation system. These are stormwater overflow tank in the combined system, sewer with storage capacity and overflow in the combined system, stormwater sedimentation tanks in the separate system, retention soil filters system in the combined and separate system and stormwater holding tanks in the combined and separate system [Sommer, H., 2007; p. 26 et seq].

Because of the anticipate costs, the ease of maintenance and the good integration into the environment systems in the separation system should be preferably designed as an open building method in earth construction. Further stormwater sedimentation tanks in the separate system as systems without permanent storage are preferable. In systems with permanent storage in the tank it comes to oxygen depletion and thus after rain events to a load on the receiving waters [Sommer, H., 2007; p. 27 et seq].

3.4.3.4 DWA-M 178

The advisory leaflet DWA-M 178 “Recommendations for planning, construction and operation of retention soil filters for further stormwater treatment in the combined and separate system“[DWA-M 178, 2005] summarizes the experiences, which were made in the dimensioning, constructional design and in the operation of retention soil filters. By filtering through a planted, biologically active soil body polluted stormwater can still be cleaned mechanical-biological on site. Basically, the statements of the leaflet can also be used for filter tanks for the treatment of stormwater runoff from non-urban roads [Sommer, H., 2007; p. 27].

For soil filters the open building method is preferable. As the optimum two-stage systems with upstream stormwater sedimentation tanks and downstream retention filter tanks as a stormwater tank retaining the first flush of stormwater or stormwater tank with overflow for settled combined sewage are specified. The filter material in the separation system should consist of coarser sand due to the higher permeability [Sommer, H., 2007; p. 27].

3.4.3.5 Other relevant advisory leaflets

In addition to the DWA notes above the worksheet ATV-DVWK-A 117 “Dimensioning of Stormwater Holding Facilities” [ATV-DVWK-A 117E, 2006] and the advisory leaflet ATV-DVWK-M 176 “Instructions and Examples of structural design and equipment of buildings of the central stormwater treatment and retention” [ATV-DVWK-M 176, 2001] also can be relevant for the treatment of road surface water.

3.4.4 BWL leaflets

The Association of Engineers for Water Management, Waste Management and Land Improvement[22] supports science, research, education and environmental protection in the fields of water management, soil protection, waste management, remediation of contaminated sites and land improvement. As a technical-scientific association this includes involving professionals from various field of environmental protection.

Similar to the DWA the Association of Engineers for Water Management, Waste Management and Land Improvement develops leaflets, which represent the technical recommendations regarding stormwater management. The BWK-M 3 [BWK-M 3, 2007] is of special relevance here. This is concerned with the drainage of immission oriented demands on combined wastewater and stormwater discharges with consideration of local conditions and provides a recommendation for action to assess the impact of wastewater discharges from sewerage systems of the combined and separation system to surface waters. The leaflet thus provides a simplified instrument for proofing to assess the effects of stormwater discharges. It would be the parameter Q, NH4-N, TSS and BSB5 examined, where the immissions are considered not point like, but linearly [Sommer, H., 2007; p. 28].

[22] Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (BWK)

4 State of the art

In the treatment of stormwater two treatment groups can be distinguished:

- centralized treatment
- decentralized treatment

The runoffs of different backgrounds and areas and therefore different matter loads are mixed together by common discharge within the stormwater channel of the separation system. The facilities at the central treatment include:

- Stormwater sedimentation tanks (SST)
- Retention soil filter
- Sedimentation tanks
- RiStWag-Separators
- decentralized treatment

The stormwater runoff of an area is treated directly at its source. It does not mix with the stormwater runoff of neighboring land. Decentralized stormwater treatment systems are shown in Figure 8:

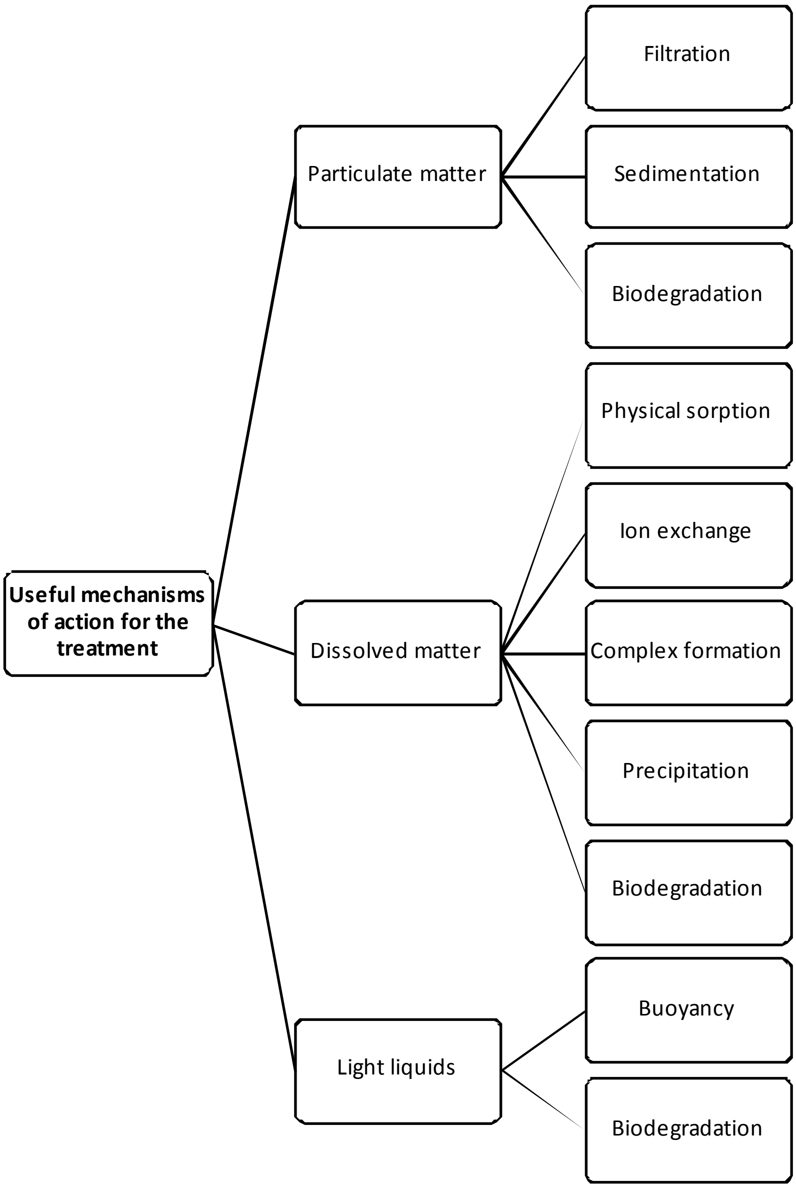

Figure 8 Overview of in decentralized stormwater treatment systems useful mechanisms of action [Feldhaus, R.; et al., no year]

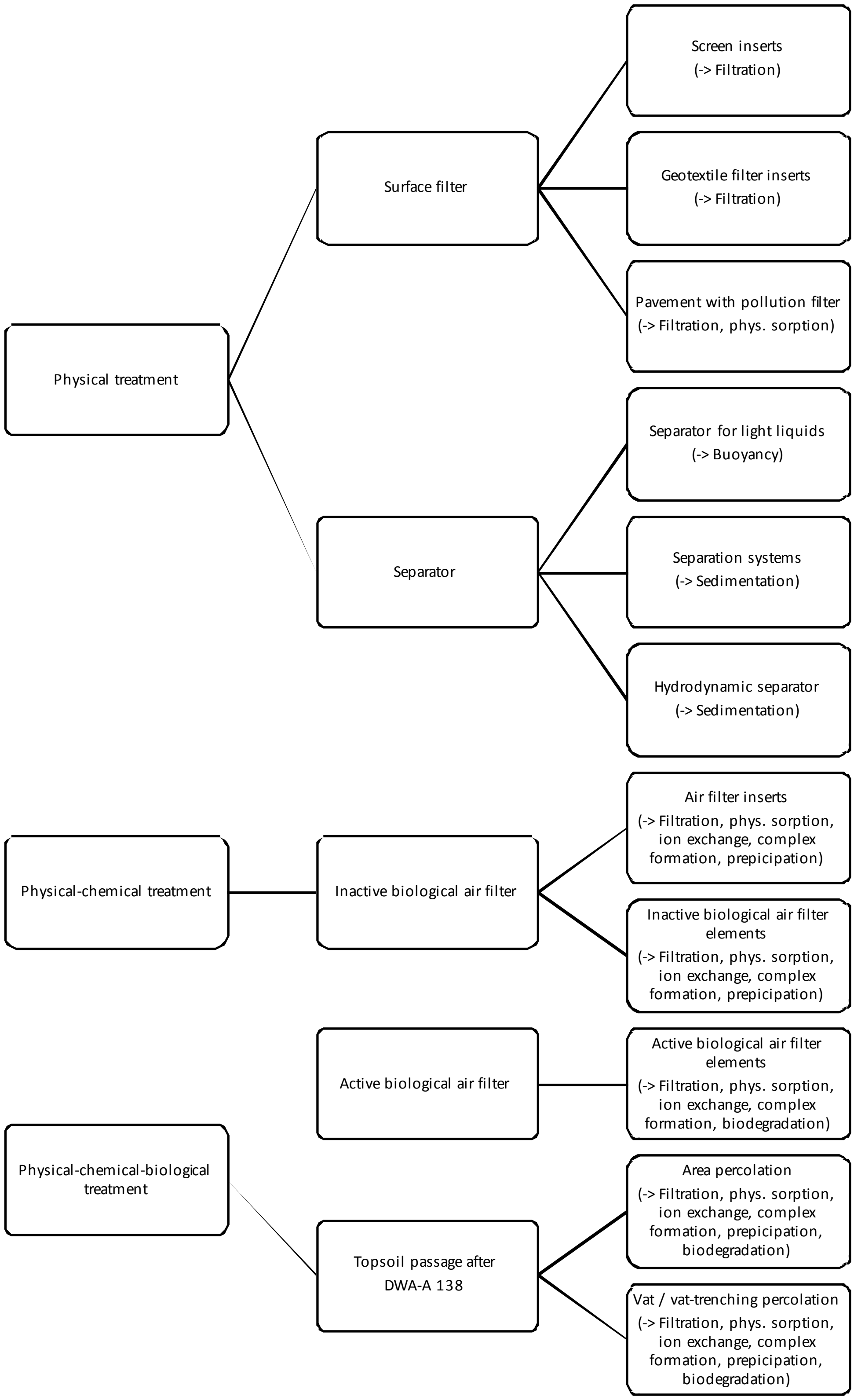

Figure 9 Typification of facilities for decentralized stormwater treatment [Feldhaus, R.; et al., no year]

In following the methods presented in the following figure are described in more detail:

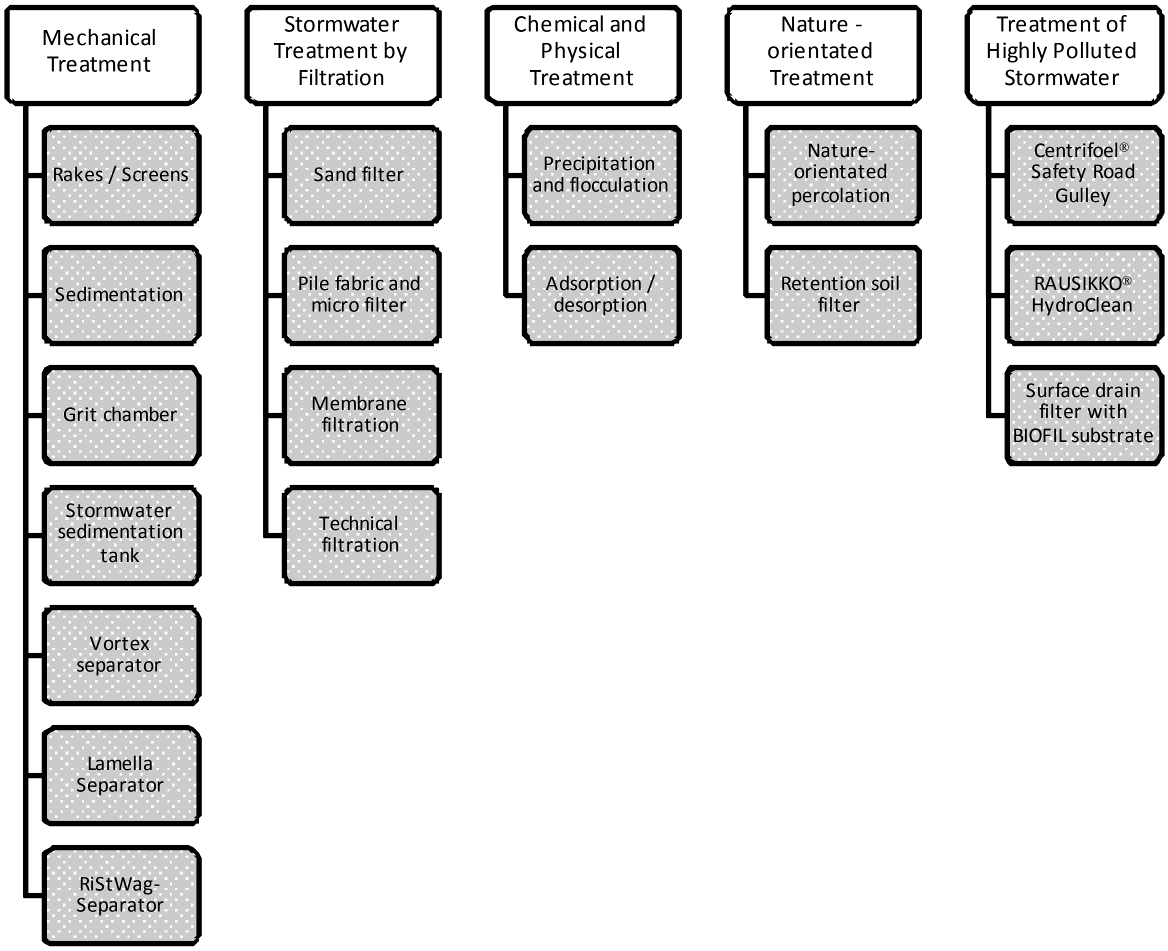

Figure 10 Presentation of methods described below

4.1 Mechanical Treatment

The planning of management of stormwater on highways is based on the RAS-Ew and in drinking water protection areas based on the RiStWag. The main form of drainage is via a percolation through the bank [Kasting, U., 2003].

To determine the manner in which treatment of road runoff is required an evaluation of the rain runoff according to ATV-DVWK-M 153 is necessary. For that purpose a classification of the watercourse takes place. Other evaluation criteria are the influences from the air, the pollution of the surface and the effects of stormwater treatment.

4.1.1 Rakes / Screens

Rakes and screens are usually the first step of mechanical treatment. They remove undissolved coarse and fine materials and protect the following components from clogging. Rakes and screens are distinguished by their passage width, by the nature of the screening body, by the structural design of the screen surface or by the type of installation. Depending on the bar spacing or the hole size, a distinction is coarse rake (about 40 – 100 mm) and fine rake (about 5 – 30 mm). Screens are divided into macro screens with mesh sizes of 0.3 mm and micro-screening with mesh sizes below 0.1 mm. Micro-screening is almost associated with filtration. Rakes are generally made of straight steel bars, which are usually arranged in a gradient of 1:2 to 1:3. To avoid blockages, machine-groomed bar screens are usually used. They differentiate between grippers- or circular-bar screens. The gripper rake conveys the screenings with a rake, which engages in the bars, strips off the screenings during the upward passage of the bars and the screenings are yield above the water. A special form of the gripper bar screen is the counter-current rake. In that system the rake moves in from behind and between the screen bars upstream and carries the screenings up, without stepping out off the rake grate. The circular-bar screen convoys the screenings by rake bars, which are attached on circulation chains. Their teeth engage to the front of the screen bars.

The cleaning capacity of a screening system depends crucially on the mesh width. Commanding variable of the dimensioning is the required screen area. This screen surface is dependent on the design flow and the receivable filter velocity, which in turn is dependent on the mesh size. For the filter velocity can be set the following values depending on the mesh size [Sieker, URL; 05/09/2011].

Table 13: Tolerated flow rate of screen systems [Sieker, URL; 05/09/2011]

Type	Mesh size [mm]	Velocity q_A [m/h]
Coarse rake	100	3,000
Fine rake	20	300
Perforated metal	20 – 1	200
Drum Screens	1	100
	0.04	30
	0.02	20
	0.01	10

The construction costs of hand-cleaned coarse rakes can be estimated at about 250 EUR per m² rake. Rakes that are cleaned by machines are much more expensive [Sieker, URL; 05/09/2011].

The annual operating costs of about 10 % of the construction costs can be recognized. The useful life of mechanical parts is 10 – 14 years, the share in the building at 25 – 40 years [LAWA, 1998].

4.1.2 Sedimentation

Sedimentation is a process under a steady decrease of solid particles in a fluid, e.g. a liquid or a gas, under the action of a force field (gravity, centrifugal force).

A particle decreases at a constant velocity as soon as lift and drag force are in equilibrium with gravity.

$$F_g = F_A + F_R \qquad \textbf{(Balance of power)} \qquad \textbf{(4.1)}$$

Settling velocities are determined through the grain shape, the size and the density of the solid particles and can be theoretically calculated. The design of sedimentation systems using theoretically determined values, however, is difficult. In practice, the density of the solid particles is very different and difficult to define, because some particles change their shape and density during settling. In reality, the settling process takes not place in still water. In addition, the settling velocities are affected by fluctuating water temperatures. Because of the difficulty of accurate determination of the different factors in practice the settling velocity by measurements in determined. The settling process used for laminar flow in which there is no mixing of adjacent stream lines can be described as follows:

The settling path of a solid particle in a laminar flow is characterized by the resultant vector of the solid particle settling velocity and the flow velocity. These results, according to Hazen, in the surface of the settling tank being equal to the quotient of waste water inflow and settling velocity. For the settling process in laminar flow the horizontal settling path L results from the flow time t_v and flow rate v, as shown in Figure 11.

$$L = v * t_v \qquad \text{[m]} \qquad 4.2$$

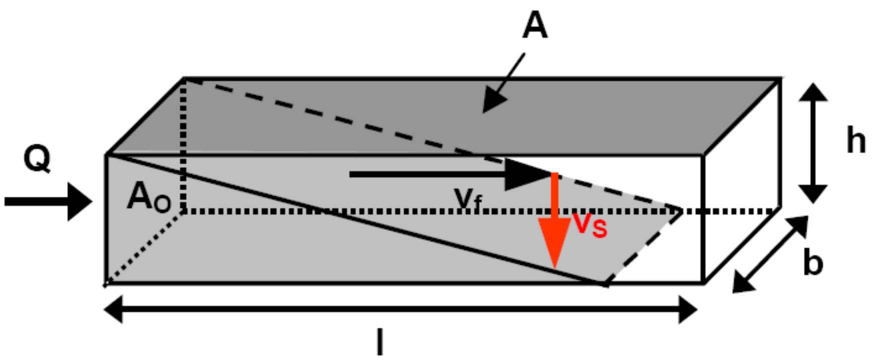

Figure 11 Settling process in laminar flow [DWA, no year]

Over the settling velocity v_s and the settling time t_s gives the height, i.e. the horizontal settling path:

$$h = v_s * t_s \qquad \text{[m]} \qquad 4.3$$

Are settling time t_s and flow time v_s equated follows:

$$t_v = t_s = \frac{L}{v} = \frac{h}{v_s} \qquad \text{[s]} \qquad 4.4$$

For a rectangular settling tank results about the inflow Q, as well as the width w and height h of the settling tank the following flow rate v:

$$v = \frac{Q}{w * h} \qquad \text{[m/s]} \qquad 4.5$$

The surface A of the settling tank results of:

$$A = l * w$$ [m²] 4.6

The required settling area is the result of Formula and Formula.

$$A = \frac{Q}{v_s}$$ [m²] 4.7

4.1.3 Grit chamber

The grit chamber is part of the mechanical water treatment to remove the sand from the water. The grit chamber is usually arranged behind the screen system. The flow velocity in the grit chamber is reduced to levels that grained suspended matter such as sand with a grain diameter of d=0.1 to 0.2 mm can sink in a particular area without flow, the sand collection chamber. A distinction is made according to type long, round and deep grit chambers. In practice grit chambers are present in combination with separator of light density material or baffles like a general solution for stormwater treatment in the separate system [Sommer, H., 2007, p. 55].

Figure 12: Grit chamber [Sewage Plant Au/Sieg, URL; 05/10/2011]

The design of grit chambers is the same as for all the sedimentation systems under the allowed flow rate. It is necessary to examine whether the surface is large enough to hold back a certain particle size. Because in the grit chamber a turbulent flow process cannot be excluded and stepped particles can be rinsed high again, additional reliabilities must be considered. In general, a dimensioning is at a critical rainfall of R_{crit} = 15 l/(s*ha_{red}) and a maximum flow rate of 0.0056 m/h wherewith grain size by 0.2 mm are largely retained [Imhoff, K., 1993]. With an assumed depth of 1.5 m, specific volumes result of about 3 – 4 m/hared. The space requirement of a grit chamber is to this approach valued at 2.25 m/ha$_{red}$ and is very low [Sommer, H., 2007, p. 55]

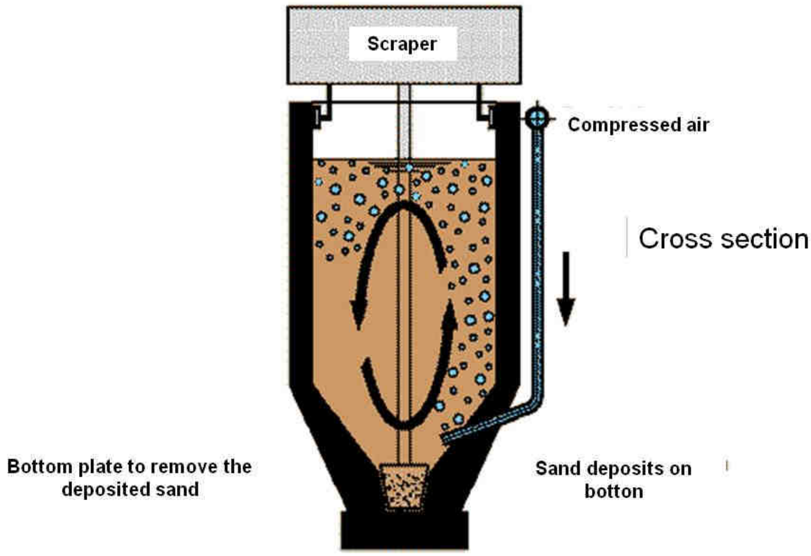

Figure 13: Aerated grit chamber [ZASE, URL; 07/10/2011]

Different grain sizes are retained as a function of the flow rate q_A to in the following figure percentages [Kalbskopf, 1966].

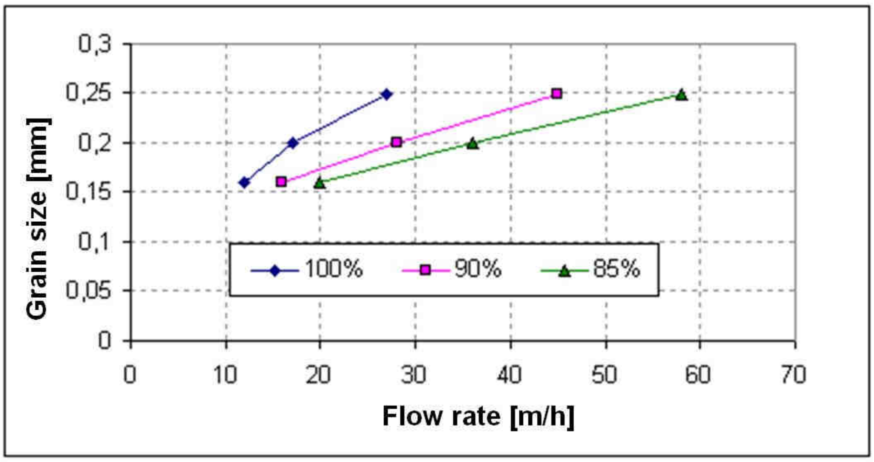

Figure 14: Separation efficiency of a grit chamber [Kalbskopf, 1966]

Grit chambers are complex structures with increased formwork effort and additional components (such as baffles, multiple parallel channels, etc.). For such structures with relatively small volumes specific costs of 2,000 EUR/m² can be assumed. The area-specific costs for a grit chamber are therefore at about 0.75 EUR/m² connected area. The operating costs of grit chambers are estimated based on stormwater sedimentation tanks to about 25 EUR/m³ tank volume. This results in very low area-specific operating by less than 0.01 EUR/m². The useful life of mechanical parts is 8 – 12 years, the part of the building at 25 – 40 years [LAWA, 1998].

4.1.4 Stormwater sedimentation tank

Stormwater sedimentation tanks clarify stormwater before discharge into receiving waters. They are used only in the separation system.

Through the expansion of the flow cross-section, the velocity of flow is reduced, so that sedimentation of deductible substances due to the resulting flow conditions is possible. The flow rate is set at q_A = 10 m/h.

There are two types of stormwater sedimentation tanks:

- Stormwater sedimentation tank without permanent storage
- Stormwater sedimentation tank with permanent storage

4.1.4.1 Stormwater sedimentation tank without permanent storage

Stormwater sedimentation tanks without permanent storage are in accordance with the design of stormwater storage tanks in the combined system according to [ATV-A 128E, 1992]. They are used when sewer infiltration water is not constantly flowing in the stormwater sewer and are arranged as either stormwater tanks with overflow or stormwater tank retaining the first flush of storm water and have generally a throttled overflow and an upstream structure with overflow. For a throttled emptying of the tank after a rain event, a short-term, temporary connection to the wastewater sewer is required to remove pollutants from the tank.

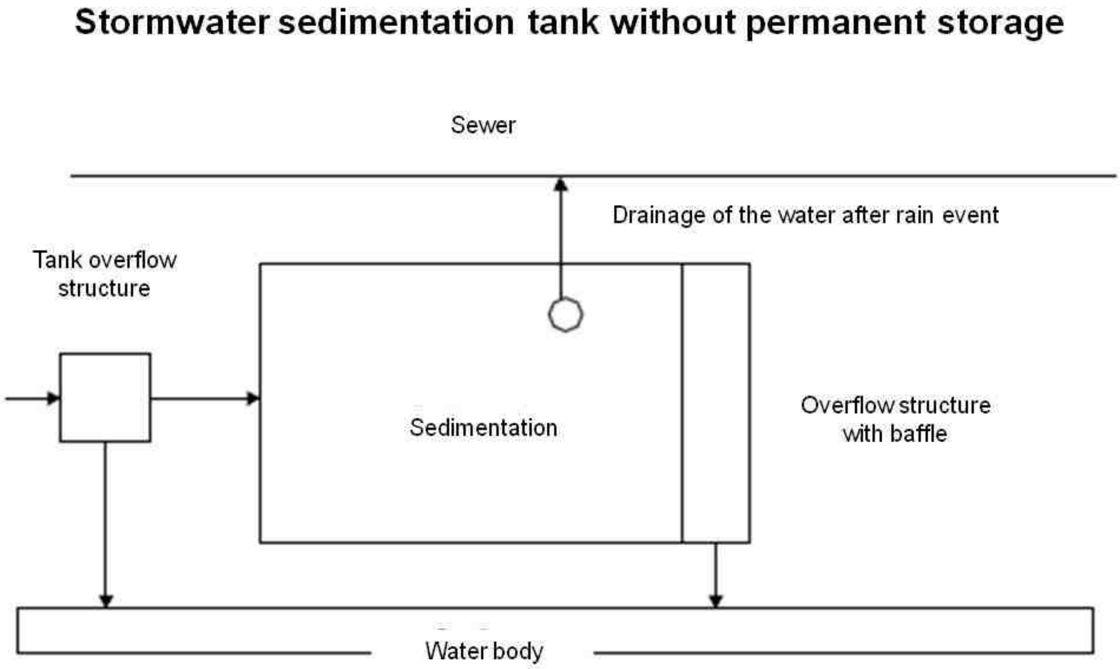

Figure 15: Stormwater sedimentation tank without permanent storage [Sommer, H., 2007, p. 58]

4.1.4.2 Stormwater sedimentation tank with permanent storage

Stormwater sedimentation tanks with permanent storage should be designed as on-line tanks according to [ATV-A 166, 1999]. However, in addition to the useful volume, a volume for sludge storage is provided. In order to prevent re-dissolution of particle-bound pollutants by anaerobic processes, ventilation openings should be arranged in closed tanks. Open stormwater sedimentation tanks usually have a nature-orientated structure as earth basin. To avoid the unwanted sludge output into the water body, permanent storage depth of 2 m should be provided.

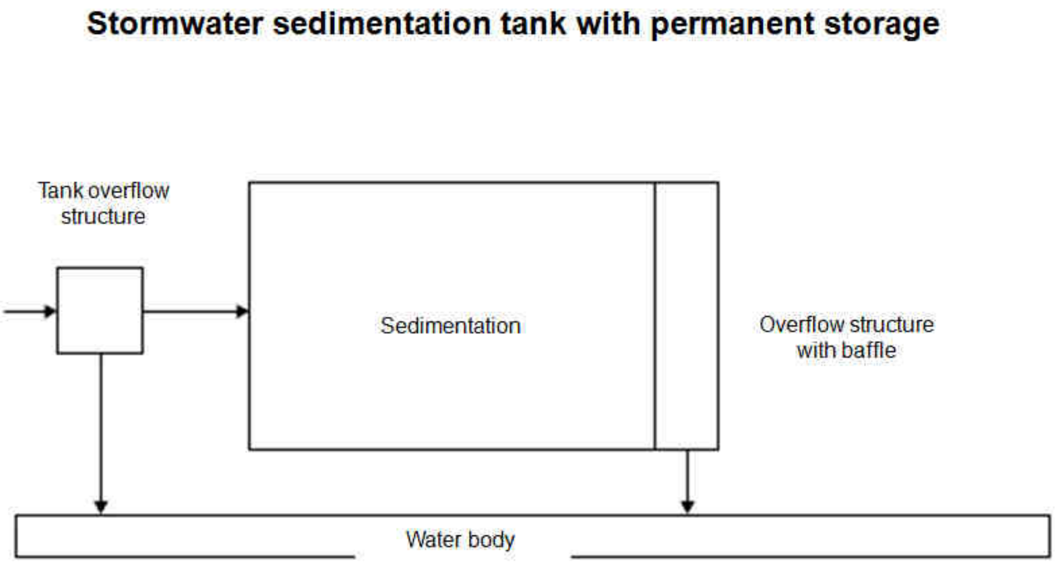

Figure 16: Stormwater sedimentation tank with permanent storage [Sommer, H., 2007, p. 57]

The construction costs for most stormwater sedimentation tanks are calculated over the useful volume.

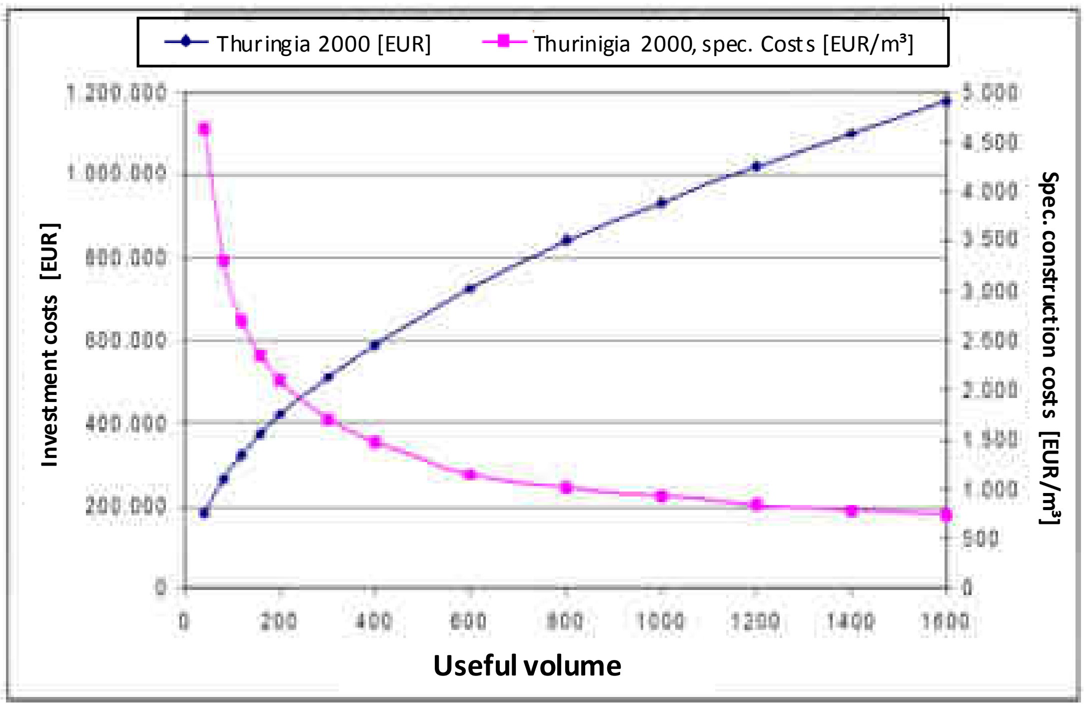

Figure 17: Cost of stormwater tanks in closed design [Thuringia, 2002]

The average useful life of stormwater tanks can be adopted for the structural part of 40 – 70 years. For the mechanical part the useful life is however only 5 – 20 years [LAWA, 1998].

4.1.4.3 Dimensioning

The determination of the effective tank surface occurs via the flow rate. There are two different approaches for stormwater tanks with or without a permanent storage:

- with permanent storage: $q_A = 7.5$ m/h
- without permanent storage: $q_A = 10.0$ m/h
- With the critical rainfall intensity and the required solid retention the design flow is calculated.

$$Q_{SST} = Q_{r_{crit}} + Q_i \qquad \text{[l/s]} \qquad 4.8$$

This allows the useful tank surface of the sedimentation chamber to be determined.

$$A_{SST} = \frac{3.6 * Q_{SST}}{q_A} \qquad \text{[m}^2\text{]} \qquad 4.9$$

In order to achieve sedimentation efficiency, minimum dimensions are given:

- Minimum depth d = 2.0 m
- Minimum volume V = 100 m³
- Velocity of flow v under the baffle = 0.05 m/s
- Distance baffle and overflow d = 0.5 m

If the volume is 100 m³ < V < 200 m³ a ratio of length to width is observed from ≥ 3:1.

If the Volume is V > 200 m³ the following values are observed:

- Ratio length L / average water depth H 10 < L:H < 15
- Ratio length L / width W 3 < L:W < 4.5
- Ratio width W / average water depth H 2 < B:H < 4

In tanks with permanent storage a buffer space for light liquids of 5 m³ and a sludge collection chamber of 1 m³/ha impermeable surface A_U is provided additionally [LUBW, 2005, p. 16].

4.1.4.4 Cleaning efficiency

Table 14 shows the cleaning effect of stormwater sedimentation tanks. The very small number of underlying samples is very problematic. For none of the parameters are more than 10 values available. Parameters, for which only a maximum of 3 values are available, are marked separately [Feldhaus, R.; et al., no year].

Table 14 Cleaning efficiency η_x for tanks with SST function ($^{*)}$: only ≤ 3 values available) [Feldhaus, R.; et al., no year, p. 29]

Parameter	TSS %	BOD_5 *) %	COD %	TOC *) %	TPH %	PAH *) %	P_{tot} %	NH_4-N *) %	N_{tot} %	Cd %	Cr %	Ni *) %	Pb %	Cu %	Zn %
Minimum	43	31	26	22	29	96	9	16	24	11	7	17	36	5	12
Maximum	85	38	72	22	80	96	74	36	33	63	77	17	82	77	84
Median	70	31	55	22	76	96	37	26	31	38	50	17	59	65	31

Because in stormwater sedimentation tanks only physical mechanism affects, the cleaning performance of SST is mixed.

The effect of stormwater sedimentation tanks has been studied by measurement rare. The limited efficacy of these systems is undeniably [Krauth, K.; Stotz, G., 2001]; [Grotehusmann, D., 2009]. In particular, the effect of stormwater sedimentation tanks with permanent storage is open to critics, because remobilization processes at high inflows, together with the displacement of heated tank contents can act rather harmful than protective in extreme situations on the water [Gruening et al., 2010-a].

4.1.5 Vortex separator

If the vortex separator is under relatively low head loss, sinking solids from stormwater runoff are separated, according to the principle of sedimentation. [Brombach, H., 1997]. The separation of the solids is taking advantage of different velocities in the vortex separator. The tangentially introduced inflow flows along the inside of the cylinder. There the flow rates are higher than in the middle of the cylinder, thereby secondary vortices near the wall are created. In these vortices a zone with very small horizontal velocities is formed, which allows a descent of pollutants. The settled solids are concentrated in a sludge channel and fed to a sewer by the sludge take-off, whereby the need to clean the vortex is eliminated. The purified water is drawn off in the middle of the cylinder between two baffles, which are flooded completely during overload of the vortex and provide the required cross-section for the emergency outlet [Sommer, H., 2007, p. 62].

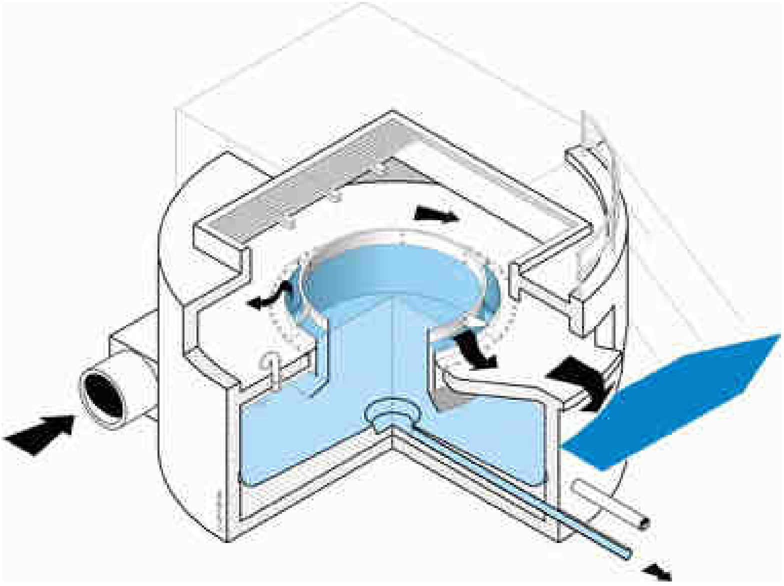

Figure 18: Vortex separator [UFT, URL; 05/12/2011]

A method for dimensioning the required volume for a vortex separator instead of a conventional stormwater sedimentation tanks was described by the LfU [LfU, 1997]. Magisterial for the hydraulic design of a vortex separation system are the local height ratios, the expected maximum inflow Q_{max} and the outflow Q_{out}.

4.1.6 Lamella separator

To improve the effectiveness of stormwater sedimentation tanks different kinds of treatment equipment can be installed. The implementation of lamella separators using parallel lamella plates increases the effective sedimentation area in existing tanks and therefore the stormwater treatment efficiency. The efficiency of a lamella separator is defined by the smallest particle diameter that is able to be settled between the lamella plates. This particle diameter depends on the density of the suspended solids and their sinking velocity [Morin, A., et al., 2008]. Therefore the layout of the lamella separator is based on the sinking velocity and the desired particle size, which should be treated. In that way the resulting number of lamella plates is a function of the particle sinking velocity, the lamella size, the distance between the lamellas, their inclination as well as the inflow rate towards the treatment system [Schaffner, J., et al., 2010].

Lamella separators mostly consist of an inflow chamber, a pumping and a flushing sump, a lamella chamber, an inflow shield, a flushing reservoir and a scum board at the outlet [Schaffner, J., et al., 2010].

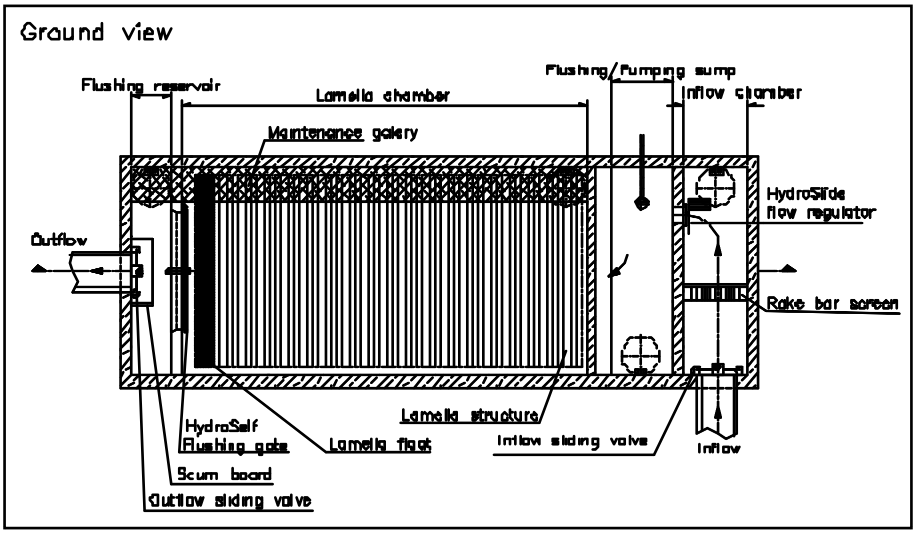

Figure 19: **Functional diagram of a lamella separator, overview [Schaffner, J., et al., 2010]**

After or during rain events the runoff enters the pumping and flushing sump before it flows across the inflow shield into the sedimentation chamber. The inflow shield guides and distributes the flow under the lamellas and creates an area from where the already settled particles will not be lifted again. In an empty tank the lamellas are in vertical position; with the rising water level the float attached to the first lamella rises and lifts the lamellas to the 45 degree working position. The water then runs through the lamellas and flows towards the outlet. After the rain event, when the inflow to the lamella system has stopped, the tank is drained by the pump into the sewer system. The lamellas fall into a vertical position which causes the wet solids attached to the lamella surface to slide down and fall to the bottom. The cleaning of the tank occurs with a flush system or similar systems [Schaffner, J., et al., 2010].

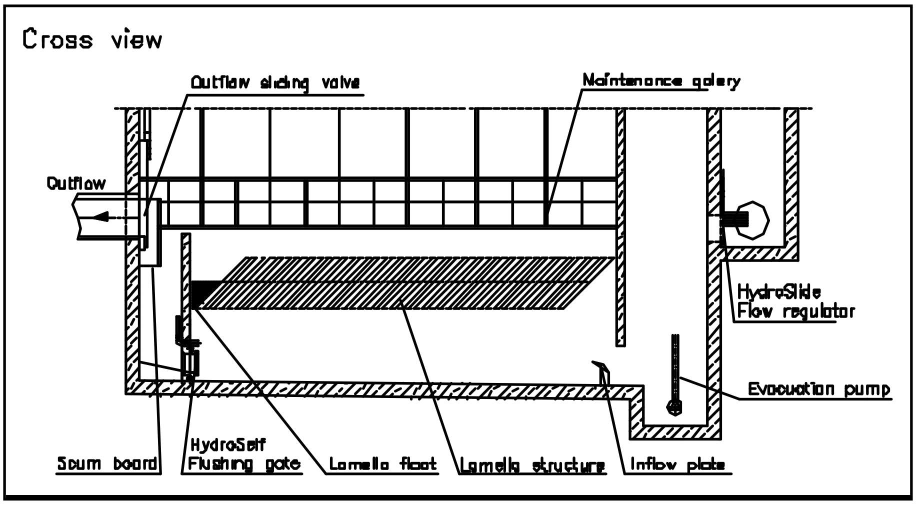

Figure 20: Functional diagram of a lamella separator, cross view [Schaffner, J., et al., 2010]

4.1.7 RiStWag-Separator

Within drinking water protection areas the management of stormwater on highways is normally done after the RiStWag. In contrast of the management of stormwater on highways outside of water protection areas, the RiStWag has further demands on the used materials and the construction work.

According to the RiStWag separators must meet the following functions for the treatment of road surface water:

- retaining the resulting on paved surfaces mechanically separable and removable water-polluting substances
- retaining large amounts of water-polluting substances, such as in tanker accidents

Basis for the design is the design flow Q_b. There are two different approaches. For both approaches, the design rainfall intensity r_{15} is set at duration of 15 minutes. If the installation in ground water protection area is under RAS-Ew, a frequency is thought of 1. This means that the rain intensity and duration is achieved or exceeded once a year. If the installation is located in the catchment area of drinking water reservoirs a frequency of 0.2 to 0.5 in dams without pre-dam and 0.5 to 1.0 at dams with pre-dam is applied. If the flow time is greater than longer than 15 minutes due to the size of the catchment area, decreases of rainfall intensity are taken into account. The required surface is calculated from the design flow and the settling velocity, thereby a minimum area of the surface of the deposition chamber of 40 m² is observed. The settling velocity is set to 9 m/s [RiStWag, 2002].

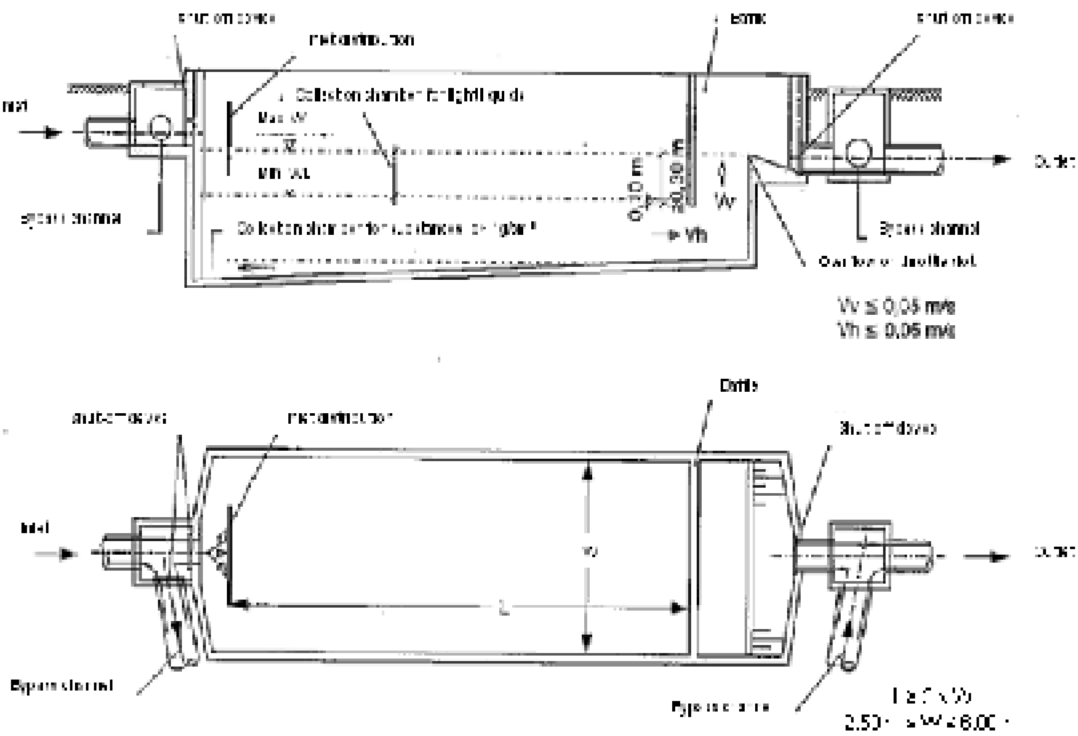

Figure 21: Schematic diagram of a separator system [RiStWag, 2002 p. 65]

To obtain a uniform flow through the tank, it should show a ratio of length to wide 3:1 or more. For individual tanks it should be between 3.0 and 6.0 m, if the tank consists of two chambers the width should be extended by 2.0 to 6.0 m. By using a suitable design for the inflow area, a flow through the entire tank width is created. Moreover, the inflow area of the separation chamber should be designed as a sludge collection chamber. The vertical velocity of flow behind the effluent baffle and the horizontal velocity of flow in the tank should not exceed 0.05 m/s. Similarly, collecting chambers for light liquid, depending on their risk potential, and materials with a greater density than water should be provided [RiStWag, 2002].

The cleaning efficiency of RiStWag-Separators has been studied at one separator, build according to the specifications of the RiStWag, in Cologne by [Kasting, U., 2003]. Table 15 presents the estimated cleaning efficiency.

Table 15 Cleaning efficiency of the RiStWag-Separator Cologne, Westhover Weg [Kasting, U., 2003]

Efficiencies [%]		
Parameter	**Efficiency (at all tested results)**	**Efficiency (at results with q_A < 4 m/h)**
TSS	13	40
COD	37	47
N_{tot}	29 1)	-
NH_4-N	-48 2)	-
Cd	11 1)	-
Cu	7	8
Pb	29	40
Zn	23	26
TPH	35	36
PAH	39	42

1) Detection limit of the inlet and outlet in the measured events is many times not reached. Reported is the median of the events in which the inlet concentration is above the detection limit.

2) It will be carried out more substances than are carried in on the surface inlet. For NH_4-N, the cause is probably the reaction of nitrogen compounds to NH_4-N.

4.2 Stormwater treatment by Filtration

In addition to mechanical sieve effects in the filtration also chemical and physical processes contribute to the cleaning of the stormwater. Because of the interactions between the particles to be removed and the filter surface also those particles that are smaller than the filter pores can also be retained [Sommer, H., 2007; p. 65].

4.2.1 Sand filter

An non-vegetated sand filter means a filter body made of washed filter sand with suitable grain size distribution, particle shape and sufficiently high calcium content, which may additionally be covered with a layer of grit [ASTRA a. BAFU (ed.), 2010]. They are equipped as slow filter with filter velocities of v_f = 0.05 to 0.2 m/h or more compact rapid sand filter (v_f < 0.7 m/h). Thereby closed rapid sand filters can reach filter velocities up to 10 – 20 m/h due to the hydrostatic pressure [Sommer, H., 2007; p. 67].

The cleaning of the stormwater is carried out mainly in the slow filter by a filter cake. This consists of fine-grained sediments and organic matter that are retained on the surface of the sand layer or be swamped. Because the cleaning efficiency declines gradually due to increasing clogging, the supreme clogging layer (50 – 75 mm) is removed regularly. This can lead to a temporary deterioration in filter performance in regarding of the contaminant removal. Due to high load the clogging in the rapid sand filter occurs faster than in the slow filter. Therefore, these filters must be backwashed in regular intervals by pumping water or a water-air-mixture in opposite directions through the filter layer. During backwashing, the polluted backwash water is to capture and treated as possible to avoid highly concentrated discharges into the sewer or water [ASTRA a. BAFU (ed.), 2010; p. 82, 86].

Contrary to the slow filters there are no experiences in the treatment of road surface water by rapid sand filters. But these are the applications successfully used in wastewater treatment for decades [ASTRA a. BAFU (ed.), 2010; p. 86].

Decisive for the space requirements of a sand filter is the dimensioning of the upstream retention volume. The space requirements may be reduced to 1 % of the connected area by a generous design of the storage basin. To reduce high costs, an optimum between small storage basins and small filter surfaces should be found [Sommer, H., 2007; p. 69].

The following Table 16 summarizes the results of measurements regarding the cleaning performance of sand filters in America.

Table 16 Measured cleaning efficiency of sand filters[Sommer, H., 2007]

Parameter	Inflow			Outflow			Efficiency		
	min.	max.	med.	min.	max.	med.	min.	max.	med.
	[mg/l]	*[mg/l]*	*[mg/l]*	*[mg/l]*	*[mg/l]*	*[mg/l]*	*[%]*	*[%]*	*[%]*
TSS	12	884	160	4	40	16	8	96	80 – 94
Ptot	0,05	1,40	0,52	0,035	0,14	0,11	5	92	50 – 75
Ntot	2,4	30,0	8,0	1,6	8,2	3,8	(-130)	84	30 – 50
organically bound nitro-gen	0,4	28	3,8	0,2	2,9	1,1	0	90	60 – 75
copper	0,03	0,135	0,06	0,016	0,035	0,025	0	71	20 – 40
zinc	0,04	0,89	0,2	0,008	0,059	0,033	50	98	80 – 90

4.2.2 Pile fabric filter and micro filters

The workings of pile fabric and micro filters are very similar and therefore listed together. They are used to remove fine particles and fine particulate heavy metals present in the road wastewater. On a beam structure of the system either a plastic or metal mesh (micro filters) with a pore diameter of between 6 and 500 µm or a pile woven fabric is installed. During the filtration operation, the stormwater flow from the outside to the inside depending on the mode of feeding. The particles are retained with the help of the tissue. The fibers of the pile fabric filter place in the filtration operation due to the water pressure, creating a finely porous filter. This also allows the cleaning of the water of finer particles. With increasing clogging of the pile fabric filters, these are cleaned using a suction mechanism. The cleaning of micro filters proceed with fixed high-pressure nozzles. The resulting sludge is sucked [ASTRA a. BAFU (ed.), 2010; p. 78].

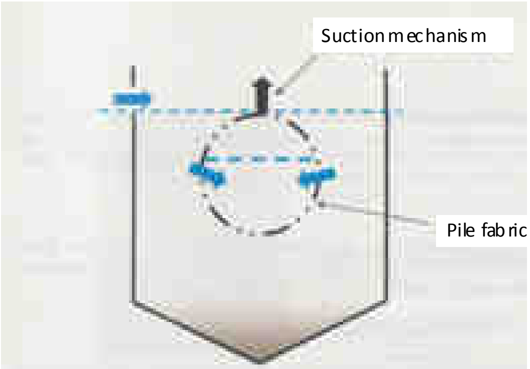

Figure 22 Schematic illustration of a system with pile fabric; loading from outside to inside [ASTRA a. BAFU (ed.), 2010; p. 81]

Pile fabric filters achieve an efficiency of 80 – 84 % for total un-dissolved solids. The efficiencies of copper and zinc amounted to 54 % (Cu) and 48 % (Zn) [ASTRA a. BAFU (ed.), 2010; p. 117]. In an experiment system designed as pile fabric filter the Swiss University Burgdorf rated the efficiency for heavy metals of 55 % to 70 % [Rudin, M.; Kaufmann, P., 2006]. For micro filters no efficient data exists, as there have been no experiments yet.

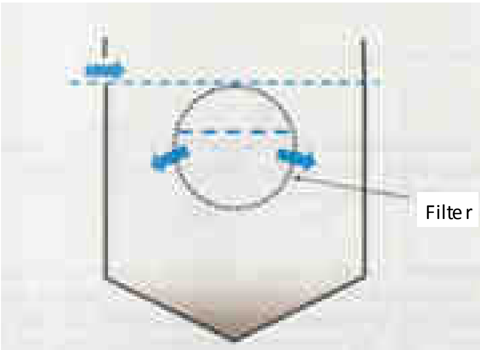

Figure 23 Schematic illustration of a system with micro filter, loading from inside to outside [ASTRA a. BAFU (ed.), 2010; p. 79]

4.2.3 Membrane filtration

During the membrane process, the wastewater and road surface water that is to be treated is forced through a membrane, thus large parts of the ingredients are separated from the water. A distinction is made for the membrane modules regarding module design, separation limit (micro-, ultra-, nano-filtration or reverse osmosis), membrane structure, filtration direction and operating mode. The micro- and ultra filtration allow a retention of suspended particles, bacteria or other microorganism. Smaller particles with a diameter of up to 5 mm can be retained by the nano-filtration. By reverse osmosis even particles with a size less than 1mm are separable. [Sommer, H., 2007; p. 85]; [ASTRA a. BAFU (ed.), 2010; p. 88].

The membrane filtration has been proven in industrial wastewater treatment and drinking water treatment and is now state of the art. The method is also suitable for the treatment of road surface water, because the installations require fewer process steps and therefore prove to be very compact. But the membrane filtration for the short term and intermittent occurring water flow is too expensive, so that currently there is no system to be operated with membrane filtration [Sommer, H., 2007; p. 85]; [ASTRA a. BAFU (ed.), 2010; p. 88].

4.2.4 Decentralized treatment by technical filtration

The study discusses the decentralized treatment by technical filtration. Due to the variety of available treatment systems by various vendors, it will be discussed superficially only. Here, a general overview of the currently available types of decentralized methods is shown.

Decentralized procedures for stormwater treatment can be divided into the following categories: filter-shaft-systems, road gullies insert and gutter systems. The most demanding task of compact systems is the compromise between the necessary maintenance and the sufficient efficiency (material retention). For a high particle retention, the most decentralized systems include filter units [Gruening et al., 2010-a; p. 13 et seqq.]. The facilities are predominantly used in urban areas where space is limited. Currently all available systems lack sound long-term experiences. [Gruening et al., 2010-b; p. 31].

Filter shaft systems can be integrated directly into the existing stormwater drains. The treatment takes place in a shaft system by a filter that is traversed from bottom to top. Some systems work with two stages and two shafts. In the shaft element of the first cleaning stage a purely mechanical cleaning of the runoffs is done. The second stage includes a filter element with a multi-layer structure [Gruening et al., 2010-b; p. 32].

Street drain inserts are designed either for direct use in existing road gullies or as a complete replacement of road gullies. They are usually characterized by a relatively simple system installation. Yet some conversion work on existing systems is required, which can lead to restrictions. Furthermore the systems are maintenance-prone, due to the variety of operating points. Besides mountable filter cartridges also geo-textile are being used. These are mounted in place of the mud bucket in the road gulley [Gruening et al., 2010-a]. However this only holds back pollutants, if a filter cake forms on the surface of the geo-textile filters. In addition, the filter can become clogged by dirt relatively quickly, which caused an additional increase in maintenance costs [Helmreich, B., 2011]. In studies of geotextile-filters in Burgdorf (Switzerland) after 55 days the clogging led to an overflow of the system [Gruening et al., 2010-a; p. 17].

Percolation channel, depending on the version, can present either open or covered with grids and navigable channel systems, which are filled with a reactive substrate. The exhaustion of the substrate mixture is expected after 20 to 25 years [Schriefer, T., 2005]

4.3 Chemical and Physical Treatment

When using chemical or physical methods to clean stormwater, one takes advantage of chemical and physical processes. These include processes such as precipitation and flocculation, but also specially coated absorber layers. Dissolved or finely dispersed substances and heavy metals can thereby transferred in a separable form and can be excreted from the water by adsorption or desorption.

4.3.1 Precipitation and flocculation

With the use of chemical precipitation or flocculation, it is possible to convert dissolved wastewater components in unresolved and therefore deductible forms. Precipitation and flocculation processes often run side by side so that a strict distinction is often not possible. At precipitation, the chemical forms with the substance to be felled a sparingly soluble salt, so that these fail into a form of precipitate and creates so-called micro-flakes. By the addition of flocculants due to different mechanism the repulsive forces between individual particles or micro-flakes will be reduced (destabilization) and a stringing together of the substances as a macro flaked are promoted. These can be removed from the road surface water by sedimentation, filtration or flotation. The performance of methods based on sedimentation can thus significantly increase [Sommer, H., 2007; p. 78]; [ASTRA a. BAFU (ed.), 2010; p. 76].

To increase the efficiency of flocculation, the dosage of flocculants should be tuned on the existing concentration and load and the dynamic flow behavior of the road surface water. Especially in flocculation processes an optimum dosage ratio of chemical to the concentration in the stormwater is required. An overdose leads to a re-stabilization of the suspension. In contrast, at a lower dosage the repulsion potential of the suspended solids will not be reduced sufficiently to allow the desired flocculation. After dosing a quick and effective intervention of the chemicals is to ensure. Thus the interference does not affect the desirable laminar flow conditions in a sedimentation tank, the flocculants can be entered directly into the water flow in the inlet channel. Because of the practically homogenous turbulent flow, precipitation of dissolved substances and the formation of macro-flakes occur [Sommer, H., 2007; p. 79, et seq.]; [ASTRA a. BAFU (ed.), 2010; p. 76].

The cleaning performance in terms of filterable solids and phosphorus by pipe-flocculation followed by filtration is increased compared to convention stormwater sedimentation tanks (Figure 24). In contrast, the elimination rates in the pipe-flocculation followed by sedimentation are lower as in the stormwater sedimentation tank. This makes clear that the cleaning performance of the precipitation and flocculation significantly depends on the mechanical cleaning performance [Sommer, H., 2007; p. 80].

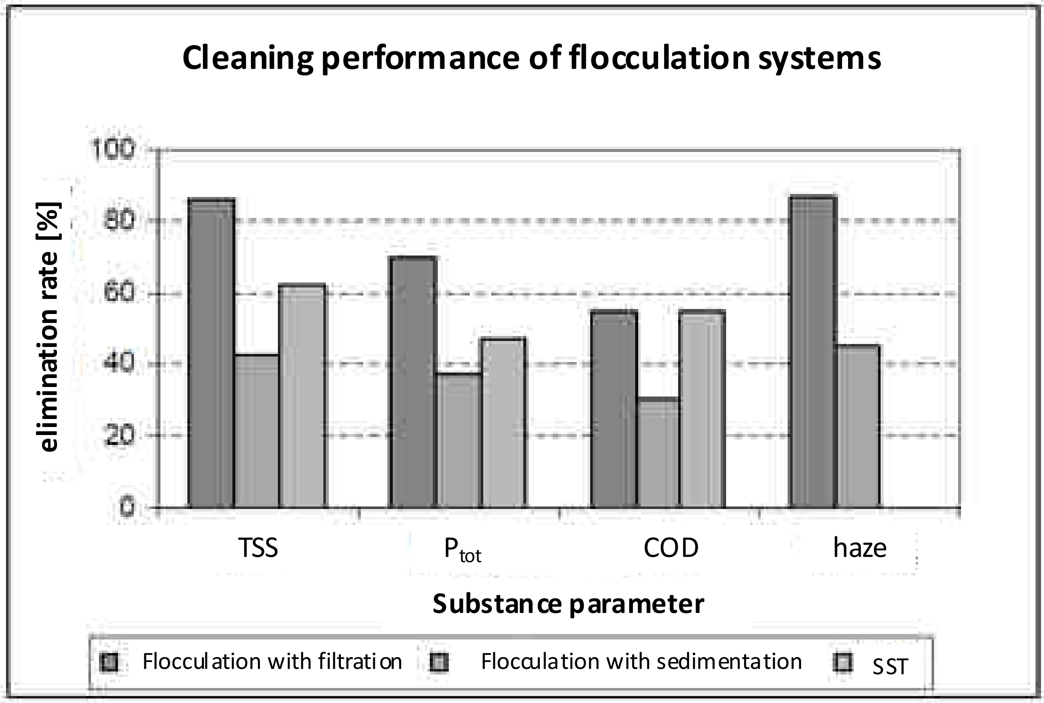

Figure 24 Cleaning performance of flocculation systems [Sommer, H., 2007; p. 81]

In addition to the sedimentation and filtration, the macro-flakes can be removed from the stormwater by a so-called air-flotation. Here, the water is saturated with compressed air at about 3.5 bar in order to give rise to small bubbles during the subsequent depressurization. These transport the macro flakes to the surface and these can be removed mechanically there. The cleaning performance is improved significantly by flotation [Sommer, H., 2007; p. 82].

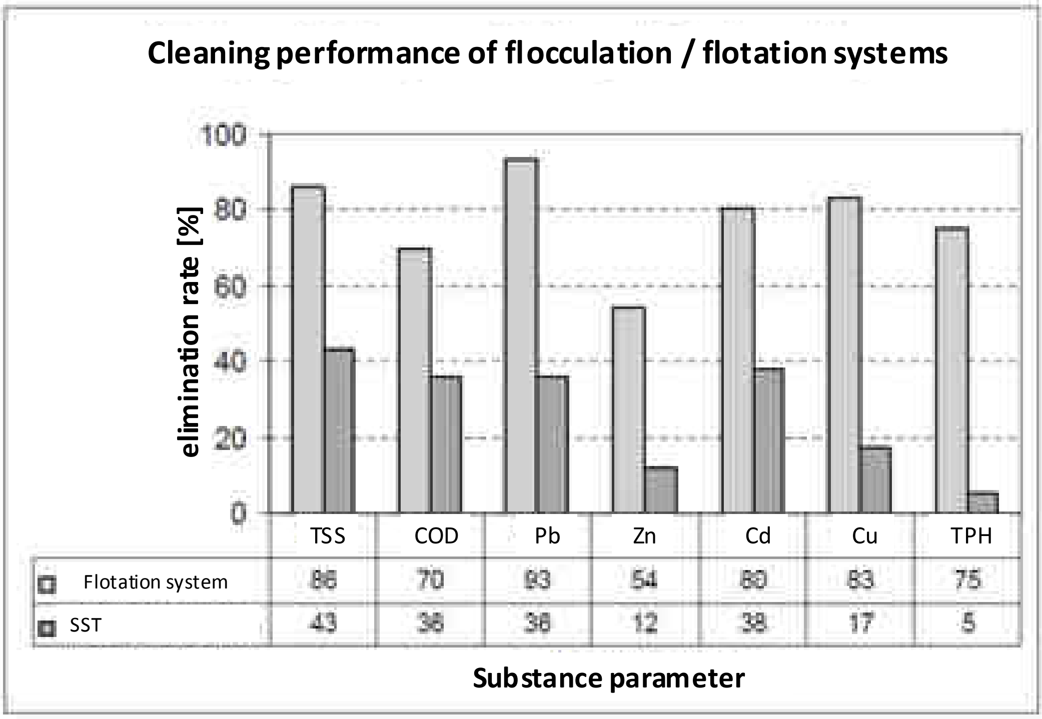

Figure 25 Cleaning performance of flotation systems [Sommer, H., 2007; p. 83]

4.3.2 Adsorption / desorption

With the help of artificial sorbents entered substances and dissolved heavy metals are reduced in the road surface water. These must be easily available, show high adsorption capacity and will also be also readily removable from the purified water. Adsorber layer of coated filter sand (zeolite, iron hydroxides, etc.) fulfill the requirements in most cases. The pH must be above pH 3, to prevent accidental detachment of iron oxide. A winter operation with zeolite is not possible because the increased salt content of the street wastewater can lead to a re-dissolution of the pollutants. Parallel to the adsorption the adsorber layer always shows a filtration effect, which further increases the efficiency further. They can be used differently in a treatment system, for example as another layer in a retention soil filter. Furthermore, they can be operated in a special filter body, as hydraulic highly loaded absorber [Sommer, H., 2007; p. 83 et seq.]; [ASTRA a. BAFU (ed.), 2010; p. 90].

For copper and zinc efficiencies are achieved by 81 % and 78 %. The efficiency of total undissolved solids is with 80 % to about 90 % relatively high [ASTRA a. BAFU (ed.), 2010; p. 119].

4.4 Nature-orientated Treatment

Nature-oriented in a particular sense means/ talks about those measure and systems that enable direct evaporation, percolation or careful draining of stormwater into surface watercourses [BSU, 2006].

Basically, after the WHG [§ 55 (2)] a site close percolation of precipitation (avoidance, reduction, percolation) is preferable to a central treatment (collection, drainage, treatment, introduction), if no treatment is required.

Within the street space discharges are collected and percolate decentralized over a wide area over the batter, ditches or troughs over the topsoil zone and fed into the natural water cycle. Part of the discharges can also evaporate through the vegetation.

In retention soil filters (RSF) heavily loaded road surface runoffs can also be treated nature-orientated. A large part of the cleaning service is also held in the vegetated soil zone.

Due to the natural design and the relatively low degree of maintenance the percolation measures of the stormwater runoff in the road area and retention soil filters can be presented and described as nature-orientated treatments.

4.4.1 Decentralized nature-orientated percolation of stormwater in the road area

The percolation of stormwater on federal, state, country or municipal roads takes place mostly flat over the batter, in ditches, in troughs or in troughs-trench systems [FGSV, 2002-b]. Sometimes shaft percolation and percolation tank systems are used.

With the percolation surface discharges should generally be avoided and a relief of the receiving waters and the groundwater recharge should be encouraged. Since the matter load of road surface water can be seen in relation to traffic load, the different percolation systems can only partially be used (see Table 17).

Table 17 Applications of different percolation systems [FGSV, 2002-b]

traffic areas	roadway traffic load (DTV)					sidewalks	parking areas frequentation	
percolation systems	DTV < 2,000 low		2,000 < DTV < 15,000 medium		DTV > 15,000 high		low	heavy
	habitation	trade	habitation	trade				
unpaved surfaces*	++	+	++	++	++	++	++	+
water-permeable paving of road surfaces1)	++	--	--	--	--	++	++	--
troughs*	++	+	++	+	++	++	++	+
trough-trench-systems*	++	+	+	+	+	++	++	+
tanks*	++	+	++	+	++	++	++	+
shaft	--	--	--	--	--	-	--	--

++ harmless
+ tolerable
- not suitable
-- not tolerable

Conditions:
* vegetated soil zone > 20 cm
minimum distance to groundwater see section 2.2
not at water protection zone I a. II
not at contaminated sites

1) applies only to construction classes V a. VI RStO

The percolation measures are indeed a standard method of road drainage [FGSV, 2002-b], but the basic requirements to the measurement determine whether and how they are executed.

The “Instructions for percolation of stormwater in the streets” name and describe this connection [FGSV, 2002-b]:

- appropriate soil and groundwater conditions
- sufficient land availability
- qualitative compatibility of percolation method or to the percolation runoff in terms of water protection (RiStWag)
- harmlessness of the percolation in relation to the roadway and other construction equipment
- backwater free drainage through adequately sized storage rooms and permanent percolation performance
- safe disposal of stormwater runoff during construction to completion

The soil structure is essential in the treatment of road runoff. One the one hand the infiltration capacity must be given, on the other hand, the infiltration capacity must not be below a maximum value of k_f = 1.0*10^{-3} m/s to allow for a cleaning within the soil passage (see Table 18).

Table 18 Guide values for the choice of the percolation method [FGSV, 2002-b]

percolation method	**infiltration capacity**
water-permeable paving of road surfaces (compacted)	$k_f > 5.4 * 10^{-5}$ m/s
area percolation (not compacted)	$k_f > 2.0 * 10^{-5}$ m/s
trough percolation	$k_f > 1.0 * 10^{-5}$ m/s (with a larger land supply also below)
trough-trench percolation (without drainage)	$k_f > 0.1 * 10^{-5}$ m/s
tank percolation	$k_f > 1.0 * 10^{-5}$ m/s

To secure a sufficient distance between the percolation system (sole) and the groundwater, a minimum distance of 1.0 m to the mean highest groundwater level is measured [FGSV, 2002-b].

[Lambrecht, B.; Fuchs, S., 2008] describe the requirements for soil or filter substrate and structure for optimum pollutant retention from road runoff [Kocher, B., 2011]:

- grain size distribution
  - sand, fine gravel fraction < 10 %
- humus
  - no requirements, the fewer the better (no mineralization, which can lead to pollutant transport)
- iron
  - because of the iron content of the road runoff there are no requirements (iron oxides / hydroxides, such as $Fe(OH)^3$ lead to good heavy metal binding)
- carbonate
  - secure pH buffering is recommended, therefore, > 5 % carbonate content and the addition of 10 – 20 % carbonate crushed sand
- thickness and area
  - 30 cm substrate thickness to prevent hydraulic short-circuit flow, filter area of 3 % A_F/A_U (at the measurement location)
- durability, portability
  - no restrictions (at carbonate-free and strong influence of vegetation, such as alleys, no measurements made)
  - applies only to road runoffs, not for roof runoffs, for example

The cleaning performance occurs mainly during the passage of vegetated topsoil [FGSV, 2002-b]. Recent studies [Kocher, B., 2011] show, that the entered pollutant loads of heavy metals in the banquet and in the upper soil areas near the edge of the road can be largely retained (see Figure 26). Prerequisite is a pH value between 6.5 to 8 with a retention of substances also during long periods, despite the preload with contaminants is given and the pH is still low. The majority of the cleaning performance is also achieved by filtration of sediment on the surface.

The “filter cake”, forming by sedimentation, contributes more to pollution adsorption than the 30 cm below banquet soil / filter material [Kocher, B., 2011].

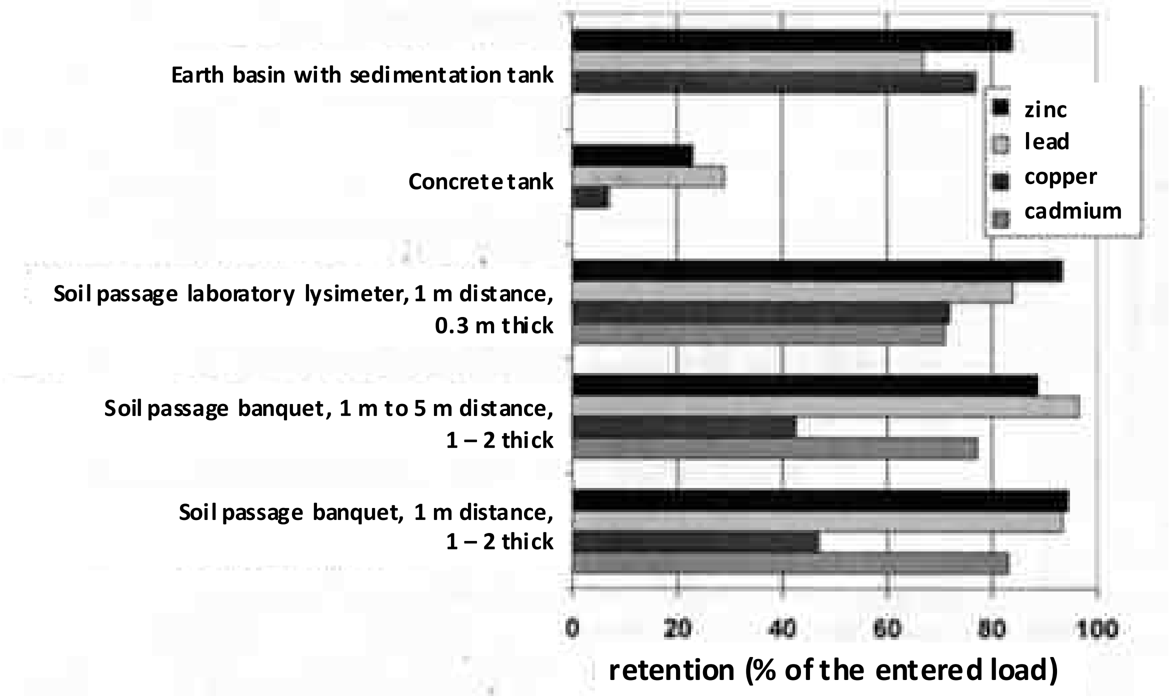

Figure 26 heavy metal retention in road soils and drainage facilities [Kocher, B., 2011]

Particle entries lead to the heightening of the topsoil (1 cm/year), which should not exceed the trigger and action values (BBodSchV) [Kocher, B., 2011]. To ensure the drainage, the banquet must be peeled off periodically. The “Directive for dealing with banquet peeling good” [BMVBS, 2010] provides a framework and nationwide uniform guidelines.

The mechanical filter effect of the banquet keeps back heavy metals very well. Copper in contrast, can hardly bind to soil solids and is eluted. On the occurrence and behavior of organic pollutants, yet very few results are available. Some potentially road relevant substances area already conducted in the annex of the WFD, some are not. In the future research and development projects produce more knowledge [Kocher, B., 2011].

4.4.1.1 Area percolation

A wide area percolation occurs either through a water-permeable paving of road surface (permitted only in low traffic load) or in close proximity to the paved area, through the banquet or the road batter. The percolation must be guaranteed without a major pile up of stormwater, because there is no above-ground storage space available. The land requirements and the appropriate land acquisition costs are very high here. The manufacturing and operating costs are low, however [FGSV, 2002-b].

4.4.1.2 Trough percolation

At the trough percolation the stormwater runoff can be temporarily stored above ground in the short term. Compared to the area percolation, a small land requirement is necessary and by the possible temporary storage, it can also be used at a lower value of k_f.

The troughs are created in earth construction and generally planted with grass, in order to obtain the necessary pore volume for the percolation ability as long as possible. In the dimensioning it is important to ensure a minimum depth of 20 cm (max. 1/5 of the trough width); with longitudinal slopes greater than 1.5 % the troughs should be created cascade shaped [FGSV, 2002-b]. The standard section (Figure 27) provides a minimum distance to the road pavers to protect the superstructure of the road surface.

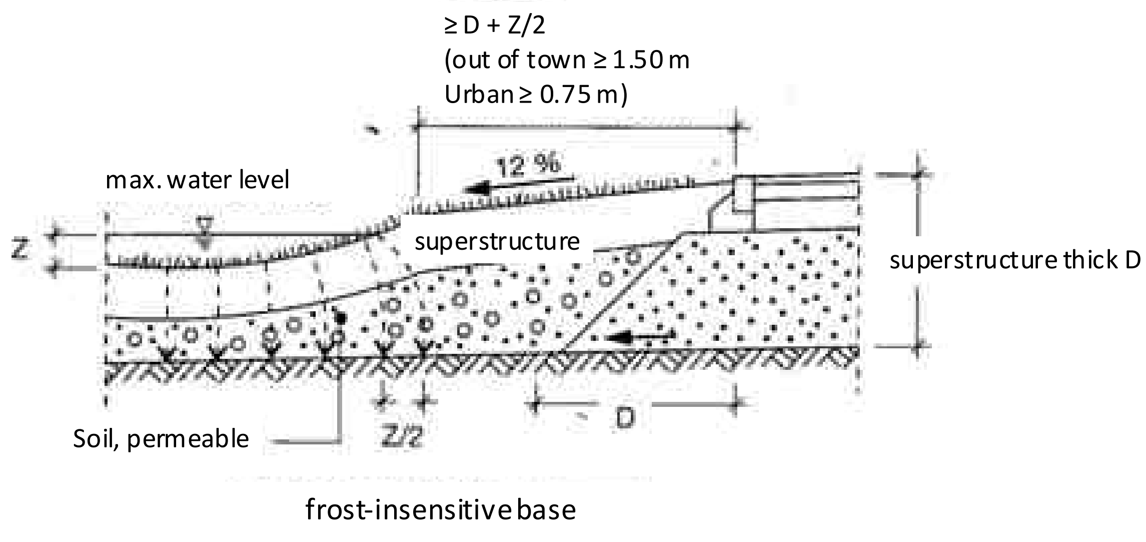

Figure 27 Banquet construction at frost insensitive base [FGSV, 2002-b]

A planting of shrubs and trees (alternating wet location) is also possible. It is important to ensure the lowest possible leave entry. When trees are planted, the stem distance should be at least twice of the bit diameter to counteract against the shadowing [FGSV, 2002-b].

4.4.1.3 Trough-trench percolation

Trough-trench percolation systems combine the trough percolation with the trench percolation (see Figure 28). The cleaning performance is similar to the trough percolation on the vegetated soil zone.

The trench acts as an underground storage space. From there, the stored water volume can percolate in the upcoming base. If there is a lack of infiltration capacity, the portion that is not percolated can be throttled over a subsoil drainage pipe. A complete drainage of the leachate due to a lack of infiltration capacity is also possible.

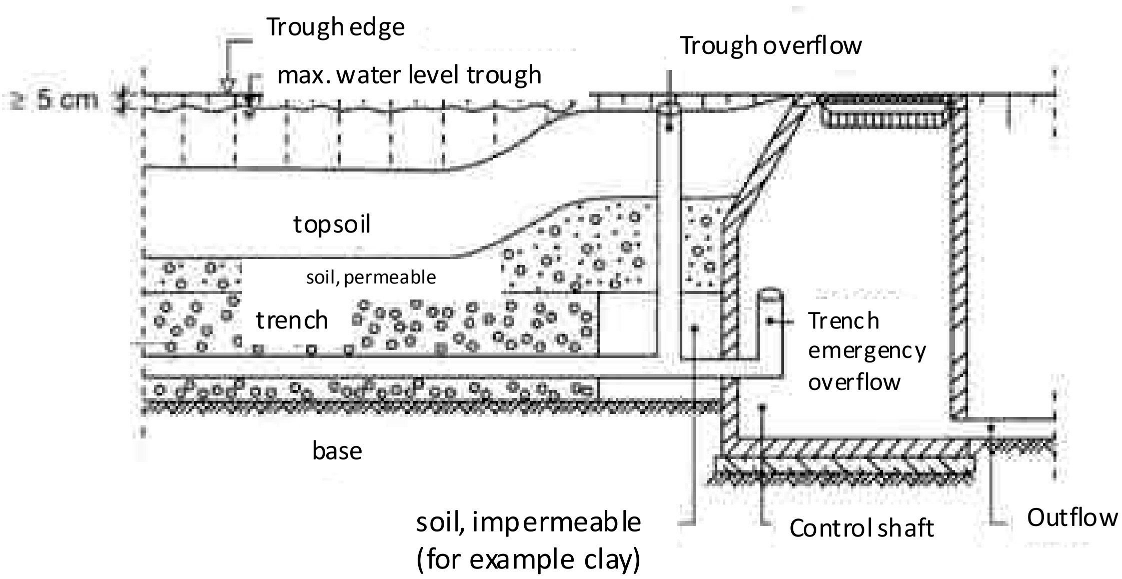

Figure 28 Longitudinal section of a trough-trench-percolation system [FGSV, 2002-b]

The percolation area demand is given as 10 % of the size of the connected area. If smaller trough areas are provided, the troughs must be provided with overflows (also because of the effects of frost). The emergency overflows also serve to safety, when the ground is frozen and cannot hold water. By grain admixtures the trough soil is increased to a permeability value of k_f = 2 * 10-5 m/s [FGSV, 2002-b].

In the DWA-A 138 more information about trough-trench systems are given[Uhl, M. et al., 2006; p. 69].

4.4.2 Central nature-orientated with retention soil filter

Retention soil filter have been successfully used to treat wastewater in the combined sewer system. For stormwater treatment in the separated sewer system the retention soil filter come more recently also used.

In the cleaning of road surface runoff, retention soil filters will be used as physical-biological method at very high requirements [Uhl, M. et al., 2006]; [Uhl, M., 2006]. The runoff is purified by sedimentation and deposition (precursor), by filtration of particulate and particle-bound substances (filter substrate) and sorption of dissolved substances and biochemical conversion. The advantages of this method are primarily the significant matter reduction of the surface waters and hydraulic reductions of the waters.

A retention soil filter system consists usually of the precursor and the retention soil filter (see Figure 29). As a precursor is a sedimentation chamber with integrated light liquid separator in order to limit the clogging risk of the filter. Stormwater sedimentation tanks are recommended as a precursor of retention soil filters in the DWA-M 178 [Uhl, M. et al., 2006].

Retention soil filters consists of a sealed filter tank with a filter layer sand (0.75 to 1.0 m powerful, 0/2 mm grain), a drainage and a control outlet. The surface of the retention soil filter is executed as a vegetation layer which should protect the retention soil filter against clogging by the shoot and root growth and contributes to filtration by the root-felt. In the regulations reed (Phragmites australis) is called as the preferred plant.

During operation, the wastewater is cached in the retention area above the filter layer and then percolates through the single-layer filter layer. In the drain layer, the treated water is supplied back to the outlet structure and from there derived [Uhl, M., 2006]. A permanent impoundment should be avoided because of the risk of clogging, but is often carried out to establish the reed (wet locations) [Roth-Kleyer, S. et al., 2010].

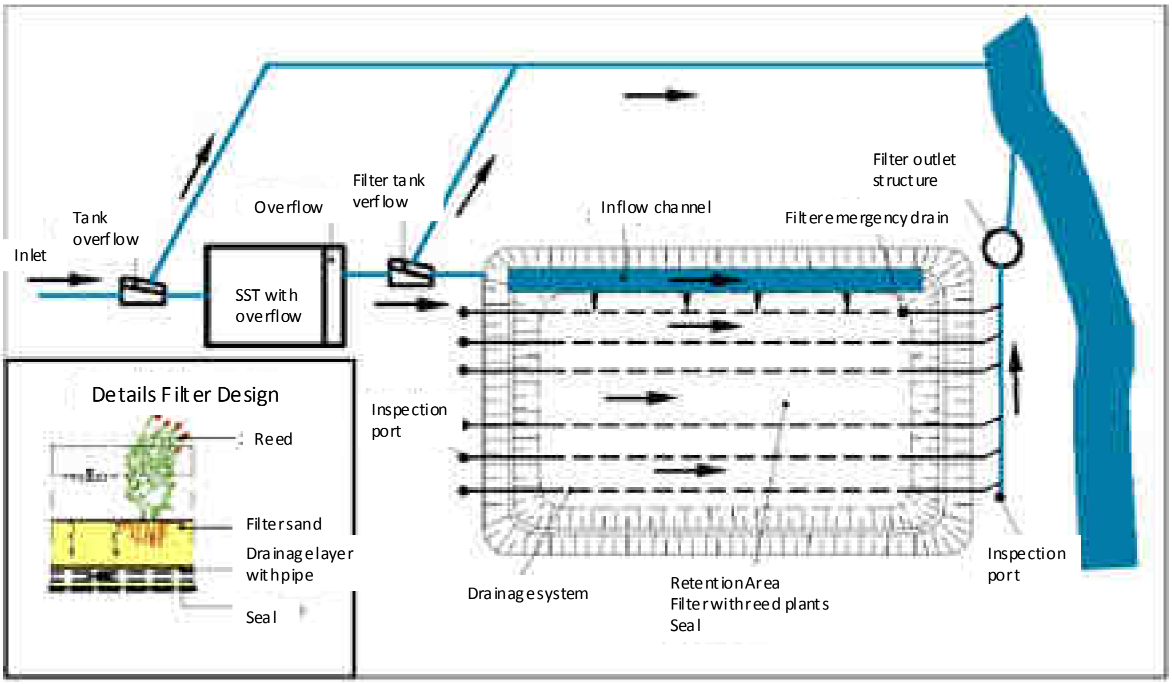

Figure 29 System sketch plan view retention soil filter system, here with upstream filter tank overflow and stormwater sedimentation tank with permanent storage [Uhl, M. et al., 2006; p. 93]

4.4.2.1 Cleaning performance

With retention soil filter can achieve compared to conventional methods such as stormwater sedimentation tanks better cleaning results (see Table 19 and Table 20).

Table 19 Cleaning efficiency of central treatment systems corresponding to [MUNLV NRW, 2004]

Type of treatment	**Level of cleaning efficiency**				
	TPH	**oxygen consuming substances, nutrients**		**heavy metals, organic pollutants**	
		particulate	**solved**	**particulate**	**solved**
Separator	++			+	
permanently filled SST (SSTwpS)	+	+		+	
not permanently filled SST (SSTwopS)					
- with restrictor flow or only intermittent restrictor flow to the tank drain after rain end	+	+	+	+	+
- with continuous restrictor flow	++	+	++	+	++
biologically active soil filter (retention soil filter)	+++	+++	+++	+++	+++
Level of cleaning efficiency: + low; ++ medium; +++ high					

Table 20 Cleaning efficiency of central treatment systems according to [Uhl, M. et al., 2006]

<table>
<tr><th colspan="2" rowspan="3">Type of treatment</th><th colspan="3">Material group</th></tr>
<tr><th>particulate matter</th><th>solved matter</th><th>TPH</th></tr>
<tr><th colspan="3">cleaning efficiency</th></tr>
<tr><td rowspan="2">SST</td><td>wopS</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>wpS</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td colspan="2">Separation systems according to the RiStWag</td><td>1</td><td>0</td><td>2</td></tr>
<tr><td colspan="2">Retention soil filter</td><td>4</td><td>2 – 3</td><td>3 – 4</td></tr>
<tr><td colspan="2">Settlement tank</td><td>4</td><td>2</td><td>3 – 4</td></tr>
<tr><td colspan="5">Level of cleaning efficiency: 0 none; 1 low …; ≥ 4 high</td></tr>
</table>

[Feldhaus, R.; et al.] give a more detailed breakdown of the cleaning performance of retention soil filter. The actual cleaning performance lies in the separated sewer system due to the lower inlet concentration presumably under the efficiency of the retention soil filter in the combined sewer system. As the available data are mostly of combined sewer systems, the results were limited transfer to the attainable efficiency of retention soil filter for stormwater treatment in the separated system [Feldhaus, R.; et al., no year].

Table 21 efficiency η_x for retention soil filter ($^{*)}$: only ≤ 3 values available) [Feldhaus, R.; et al., no year, p. 29]

Parameter	TSS %	BOD_5 *) %	COD %	TOC *) %	P_{tot} %	NH_4-N *) %	NO_3-N *) %	N_{tot} %	Ni *) %	Pb %	Cu %	Zn %
Minimum	48	50	35	53	29	58	43	12	84	85	85	90
Maximum	95	95	95	92	87	95	100	54	98	85	85	92
Median	90	89	76	70	82	82	100	27	91	85	85	92

A comparison of existing test results be made very difficult by the fact that the retention soil filter units differ in structure, type of precursor, filter substrate and filter vegetation [Feldhaus, R.; et al., no year].

[Kasting, U.,] examined for the first time in 2002 with the help of semi-technical soil filters (lysimeters) the efficiencies of different heavy adsorption, sandy filter substrates for central treatment of road runoff. For particulate and dissolved heavy metals significant cleaning effects have been determined. For weak adsorption substrates, the retention of dissolved heavy metals was significantly lower. PAHs could be kept well back by filtration. TSS cannot be held fully back. They are transported through the filter and discharged. For chloride and phosphate no or only minor cleaning efficiencies can be achieved [Kasting, U., 2003].

There is a need for research on [Kasting, U., 2003]:

- Determination of the cleaning performance of large-scale retention soil filter especially under the aspect of long-term operation
- Investigations of operational considerations (clogging) in retention soil filter (especially the development of a method for testing of filter substrates compared to the salt load)
- Increase of the data set to cleaning performance of different treatment systems in order to derive statistically reliable ranges of efficiencies for the system types

- Systematic studies on the optimization of the sedimentation process sedimentation systems to derive guidelines for sizing, which promise a high load reduction of these systems

In a research project, [Dobner, I.; Holthius, J.-U.,] worked on the development of a “high performance plant filter”. Using an also for traffic flows representative heavily loaded pollutant mixture, different plants, symbiotic fungi (mycorrhiza) and filter materials were tested and their sustainability determined (lysimeter studies).

Compared to existing facilities to treat road runoff was the cleaning performance of soil filters (for water-soluble groups of pollutants such as PAH or TPH) using plants of mycorrhiza and optimized substrates (silicate colloid / organic content; to a lesser degree pumice lava / humus) are significantly increased. Also worst-case conditions (e.g., accidents) were tested and a representative of novel pollutants. The cleaning capacity remained at the worst case doping with the strict requirements of the Drinking Water Directive [Dobner, I.; Holthius, J.-U., 2007; p. 94].

The studies illustrate the potential of plants and their companies in retention soil filter. The planting contributes to heavy metal accumulation (phytoextraction) and leachate reduction (transpiration). In particular, reed canary grass[23] (Phalaris arundinacea) was characterized by very good growth and formed together with Tonquil[24] (Juncus effuses) a shallow, dense root [Dobner, I.; Holthius, J.-U., 2007].

Research need, [Dobner, I.; Holthius, J.-U.,] see further at the road salt-inducted clogging risk; see [Kasting, U., 2003], as well as to the:

- Cleaning efficiencies to real, particle-bound road runoffs and anionic substances as well as maximizing the hydraulic connection conditions

- The durability of the stability of the plant community over several vegetation periods

- Size of influence of mycorrhizal fungi at the removal of pollutants in periodically wet soil of a filter (direct or indirect effects on the plant)

[23] Rohrglanzgras

[24] Flatter-Binse

From the perspective of the growth technology further research project efforts could improve the efficiency of the vegetation layer in retention soil filters. The survey by [Roth-Kleyer, S. et al.,] makes clear that the so far in the German wastewater technical regulations and manuals provided planting with mono-structured reeds can hardly establish in everyday practice, and cleaning performance will be minimize probably thereby.

The retention soil filters are often operated with permanent storage, to supply the filter vegetation sufficient with water. The present studies on the development of the retention soil filters and the regulations, however, based on freely ventilated filter systems. Because of this, a review of the actual cleaning power of retention soil filters under realistic conditions is required [Roth-Kleyer, S. et al., 2010].

It must be checked in particular, to what extend aerobic purification methods in retention soil filters are reduced by the permanent storage or whether one must return to a rule application of retention soil filter without permanent storage operation [Roth-Kleyer, S. et al., 2010].

In practice survey by [Roth-Kleyer, S. et al.,] mainly operators of retention soil filters in the combined wastewater responded, so that a separate analysis of retention soil filters in the treatment of separation sewer systems and road runoffs was omitted.

In order to obtain a nationwide overview of the state of soil filter retention technique, the results of [Roth-Kleyer, S. et al.,] should be continued and expanded. To optimize the retention soil filter technique for the treatment of road runoff here practice targeted surveys should be conducted.

The previously usually proposed und mostly coming to use reed is of vegetation technical and especially in view of the overall operating system regarded as inappropriate.

Instead, the plant spectrum must be supplemented by a further range of species, in order to obtain a site-adapted and best cleaning performance of the vegetation layer. It would allow to understood the vegetation layer not only as a static moment in the form of mono-structured plant populations, but as to the specific site conditions dynamic personalized vegetation system (dynamic vegetation, succession) [Roth-Kleyer, S. et al., 2010].

Research efforts should lie here on a detailed study of the plant composition (vegetation companies), which establish themselves in the course of succession on the retention soil filter. Because of their ability to adapt to extreme habitats such as retention soil filters, they could offer to equivalent bioengineering properties alternatives that operate with less effort while allowing a better integration into the landscape.

One example is the Great Nettle (Urtica dioica). It is often found as a result of vegetation on retention soil filters [Roth-Kleyer, S. et al., 2010], has wide location amplitude and also has a lot of bioengineering properties that they could predestine for a planned use on retention soil filters.

4.5 Treatment of Highly Polluted Stormwater

Stormwater from road surfaces is often heavily loaded with various contaminants. A discharge to water bodies or a percolation without pre-treatment is therefore usually not recommended. There are several decentralized procedures (as in Table 22), which can be used in addition to the usual treatment systems such as stormwater sedimentation tanks, retention soil filter or similar systems.

Table 22 Overview of decentralized stormwater treatment systems according to [Leisse, R., 2008]supplemented by [Feldhaus, R.; et al., no year]

System	Type	Specific investment costs	Efficiency tests
physical treatment			
geoSTON® [Klostermann Ltd. & Co. KG concrete plants]	Pavement with pollution filter	approx. 15.00 €/m² to 22.00 €/m²	DIBt test
Aquafil [Concrete plant Lintel Ltd. & Co. KG]	Pavement with pollution filter	approx. 10.00 €/m² to 20.00 €/m²	laboratory
Gulley with wet sludge trap [DIN 4052-1 to 4]	Sedimentation system	ca 0.40 €/m² to 0.60 €/m²	laboratory
Separation road gulley [ACO Drain Passavant Ltd.]	Screen insert, Sedimentation system	n / a	in situ, labora-tory
Geotextile filter bag [P. Schreck fleece and filter technology Ltd.]	Geotextile filter insert [retrofit kit]	approx. 0.65 €/m² to 0.95 €/m²	in situ
Light liquid separator [according to DIN 1999-100, -101; DIN EN 858-1, -2]	Light liquid separator, sedimentation system	n / a	DIBt test
Parking area drainage system[25] [Freylit Environmental Engineering Ltd.]	Light liquid separator, sedimentation system	n / a	n / a
RAUSIKKO® System [REHAU Ltd. & Co.]	Light liquid separator, sedimentation system	approx. 4.45 €/m² to 5.70 €/m²	n / a
Centrifoel® Safety road gulley [Valperz-Scarabaeus Ltd.]	Screen insert, Light liquid separator, sedimentation system	approx. 5.00 €/m² to 5.40 €/m²	laboratory
Sedimentation system MSA [Mall Ltd.]	Light liquid separator; hydrodynamic separator	approx. 2.05 €/m² to 5.20 €/m²	laboratory

[25] Parkflächenentwässerungssystem PFE

Lamella clarifier MLK-R [Mall Ltd.]	Light liquid separator, sedimentation system	approx. 2.20 €/m² to 7.50 €/m²	laboratory
physical-chemical treatment			
INNOLET® [Funke plastics Ltd.]	Screen insert, air filter inserts, sedimentation system [retrofit kit]	approx. 3.50 €/m²	in situ
Rigo®-clean + Sedi®-pipe + Sedi®-substrator [Franconian pipe plants Bros. Kirchner Ltd. & Co. KG]	Screen insert, light liquid separator air filter inserts, sedimentation system	approx. 9.00 €/m² to 17.00 €/m²	laboratory
New development TUM et al. [TU Munich / Hans Huber Ltd. / HydroCon Ltd.]	Sedimentation system, hydrodynamic separator, air filter insert	approx. 15.00 €/m² to 17.00 €/m²	in situ
Substrate Filter Shaft [Heitker Ltd.]	Sedimentation system, light liquid separator, air filter insert	approx. 4.00 €/m² to 8.00 €/m²	n / a
Up-Flo filter [Hydro International]	Sedimentation system, light liquid separator, air filter insert	n / a	n / a
RAUSIKKO®-HydroClean [REHAU Ltd. & Co.]	hydrodynamic separator, air filter insert, light liquid separator [retrofit kit]	approx. 4.60 €/m² to 10.00 €/m²	in situ
physical-chemical-biological treatment			
INNODRAIN® [Mall Ltd.]	separation system, biological active air filter element	approx. 25.00 €/m² to 35.00 €/m²	in situ
Terra-Regenspeicher® [Mall Ltd.]	biological active air filter element	approx. 11.50 €/m² to 13.80 €/m²	laboratory

ECO-Soil filter [Concrete plant Müller Ltd. & Co. KG]	biological active air filter element	approx. 13.55 €/m² to 17.30 €/m²	DIBt test
D-Rainclean®- percolation trough [Funke plastics Ltd.]	biological active air filter element	approx. 8.50 €/m² to 60.70 €/m²	DIBt test
Surface drain filter with BIOFIL substrate [Heitker Ltd.]	biological active air filter element	approx. 4.00 €/m² to 5.00 €/m²	laboratory
Surface percolation [according to DWA-A 138]	surface percolation	approx. 2.50 €/m² to 30.00 €/m²	in situ
Trough percolation [according to DWA-A 138]	trough- or trough-ditch-percolation	approx. 3.50 €/m² to 7.50 €/m²	in situ
Trough-ditch percolation [according to DWA-A 138]	trough- or trough-ditch-percolation	approx. 12.50 €/m² to 30.00 €/m²	in situ

So far standardized test methods for evaluating the efficiency of decentralized systems for stormwater treatment is only developed for the following systems or system components by the German Institute for Construction Engineering:

- Surface coverings and substrates for the treatment of polluted stormwater runoff
- Light liquid and coalescence separator

Accordingly, the studies executed or commissioned by the respective system manufactures are different concerning the examination and evaluation methods, the hydraulic load and the considered substances and their concentration. A comparative comparison is therefore only of limited significance [Feldhaus, R.; et al., no year Chapter 4].

Table 23 Measured cleaning performance of decentralized stormwater treatment systems according to [Leisse, R., 2008]

System	**TSS**	**COD**	**P_{tot}**	**NH_4**	**NO_3**	**Cd**	**Zn**	**Cu**	**Pb**	**PAH**	**TOC**	**TPH**
	[%]	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*	*[%]*
Physical treatment												
geoSTON® [Klostermann Ltd. & Co. KG]	98.6					96	56.6	95.9	99		89.3	
Aquafil [Concrete plant Lintel Ltd. & Co. KG]						88.6	95.4	93.5	98.1		97.5	
Gulley with wet sludge trap [DIN 4052-1 to 4]	20 – 35											
Separation road gulley [ACO Drain Passavant Ltd.]	40 – 55											
Geotextile filter bag [P. Schreckfleece and filter technology Ltd.]	80						70	58	73			
Centrifoel® Safety road gulley [Valperz-Scarabaeus Ltd.]	99.6					90.6	97.9		97.5			95.4
Sedimentation system MSA [Mall Ltd.]	80											
Lamella clarifier MLK-R [Mall Ltd.]	80 – 90											
physical-chemical treatment												

INNOLET® [Funke plastics Ltd.]	48	48	40				48	32				
Sedi®-pipe [Franconian pipe plants Bros. Kirchner Ltd. & Co. KG]	57											
New development TUM et al. [TU Munich / Hans Huber Ltd. / HydroCon Ltd.]							94.6	95.2	86.6	96.7		
RAUSIKKO®-HydroClean [REHAU Ltd. & Co.]	94			91			86	84	82		91	
physical-chemical-biological treatment												
INNODRAIN® [Mall Ltd.]	81	63	45				81	45				
Terra-Regenspeicher® [Mall Ltd.]							33.6	66.8	80.8			
ECO-Soil filter [Concrete plant Müller Ltd. & Co. KG]	99	80	60	90	30	99	95	99	99	90		99
D-Rainclean®- percolation trough [Funke plastics Ltd.]	99	80	60	90	30	99	95	99	99	90		99
Surface drain filter with BIOFIL substrate [Heitker Ltd.]	80 – 99	70 – 95	60 – 80	60 – 99						80 – 99		
Surface percolation [Nadler, A.; Meißner, E., 2001]						55	88	52	86			
Trough percolation [LfW Bavaria, 1999]; [Nadler, A.; Meißner,	90 – 91.5						84 – 86	59 – 70	88 – 94			

E., 2001]												
Trough-ditch percolation [Sommer, H., 2007]	87	68	48				87	48				

4.5.1 Centrifoel® Safety Road Gulley

The Centrifoel®-Safety Road Gulley of ROVAL environmental technologies can be used to treat stormwater of yard-, park-, industry- or traffic areas. Afterwards there may be a discharge to a percolation system, to a close local water body or into a storm sewer. The gulley is a compact device made of polyethylene (PE) and includes a multi-chamber cleaning system [Feldhaus, R.; et al., no year; Annex 3].

Below the cast cover in the inlet area there is a leaves and coarse dirt filter basket. Below is the preliminary cleaning chamber with sludge trap and overflow device. The overflow leads directly into the multi-chamber system arranged below, separated from the upper chamber by a removable floor.[Feldhaus, R.; et al., no year; Annex 3]

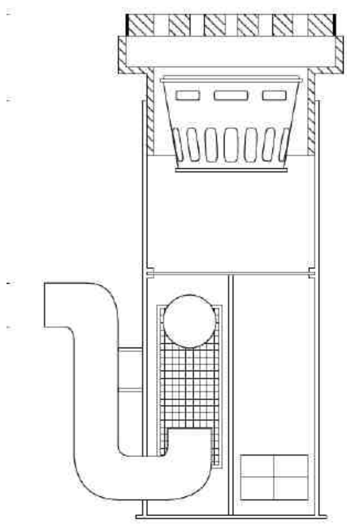

Figure 30 Structure of CENTRIFOEL® [ROVAL, URL; 07/02/2011]

The first chamber is used as the main storage for light liquids such as oils, gasoline etc., the second sedimentation chamber includes a fine-mesh filter (coalescence filter) and the third chamber is equipped with a lock valve in the form of a calibrated ball cap in front of the outlet [Feldhaus, R.; et al., no year; Annex 3].

There are both a filtration and a sedimentation and a separation of light liquids and suspended solids [Feldhaus, R.; et al., no year; Annex 3].

The stormwater of the connected area flows through the cast cover in the coarse dirt filter basket. In the preliminary cleaning chamber suspended solids settle down and water flows through the overflow into the first chamber of the underlying multi-chamber system. The first chamber is used to calm the water; it holds further sedimentation of fines. Entrained light liquids rise and gather at the water surface. Between the first and second cleaning chamber is an opening. In the second chamber further sedimentation and oil accumulation take place. Before the water enters the third chamber, it flows through a fine filter, where other suspended particles and small oil particles are filtered from the water. The rest of the oil passes through the fine filter in the third chamber and accumulates on the water surface.

If the oil content increases in the third chamber, the water level falls and with the water level the ball cap drops, which is not floating on oil due to their calibrated density. If the oil content in the third chamber is too high, the ball closes the outlet and an oil discharge is no longer possible. A cleaning of the systems is carried out with suction and flushing vehicles. Up to 400 m² sealed area can be connected [Feldhaus, R.; et al., no year; Annex 3].

The following efficiencies can be achieved with the gulley according to the manufacturer:

Table 24 Cleaning efficiency of the CENTRIFOEL® Safety Road Gulley [Feldhaus, R.; et al., no year; Annex 3]

Parameter	Efficiency [%]
TSS	99,59
Pb	97,52
Zn	97,85
Cd	90,56
TPH	95,36

4.5.2 RAUSIKKO® HydroClean

The RAUSIKKO®-HydroClean (formerly 3P-Hydrosystem) is a filter system that is installed ready for connection in a control shaft. Through various filter media, various types of pollution are cleaned [REHAU, 2010].

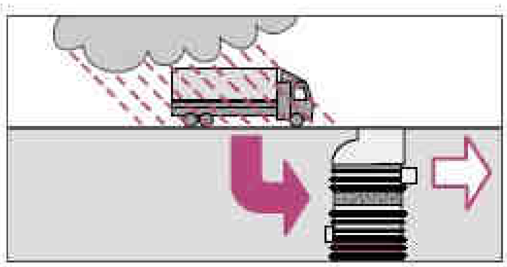

Figure 31 Example of application [REHAU, 2010; p. 34]

The cleaning components are integrated into compact filter elements. A filter set consists of four filter elements. To ensure a fast and the same time irreversible pollution backing, various cleaning components are used in different proportions [REHAU, 2010].

The stormwater is discharged at the lower end of the shaft. By a deflection help the water is diverted tangentially and forms a circular flow (hydrodynamic separator). The laminar radial flow supports the sedimentation of particles of the sand fraction on the funnel-shaped bottom of the chamber, shown in Figure 32. The sediments enter through an opening in the radial separator in the sludge trap at the bottom of the shaft, from where they can be extracted when needed. By the flow stabilization in the sludge trap and the funnel-shaped inlet a backwash is effectively prevented even during heavy rain events [REHAU, 2010].

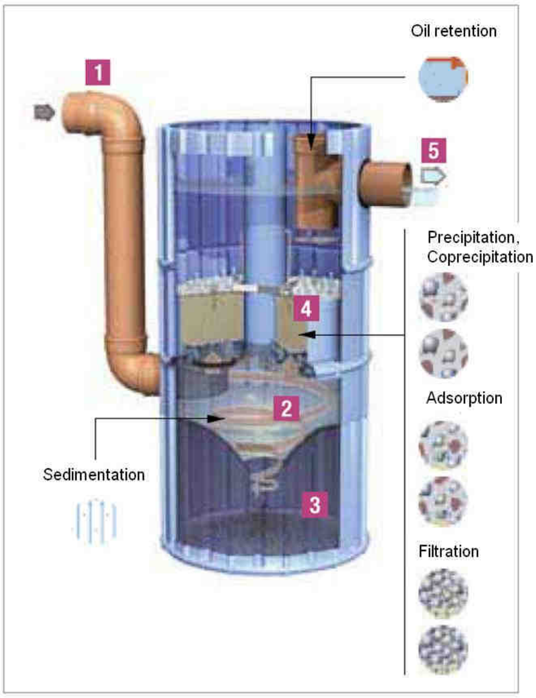

Figure 32 Structure cleaning module and function [REHAU, 2010; p. 36]

The water, mostly pre-cleaned of solids, then flows through the filter elements in the middle of the shaft from the bottom up. A large part of the dissolved contaminants are precipitated and adsorbed. At the same time, the elements act as a filter for suspended solids, which are still in the stormwater. The filter is easily replaced if necessary. The clean water above the filter elements then passes an oil-retention and then flows through the outlet into the downstream percolation system or into the receiving water [REHAU, 2010].

With the RAUSIKKO® HydroClean cleaning system the following cleaning performances can be achieved:

Table 25 Cleaning performance of the RAUSIKKO® HydroClean cleaning system [REHAU, 2010; p. 38]

Parameter	Unit	Main road		HydroClean
		from	to	Effluent quality
		sum parameters		90 - percentile
electrical conductivity	[µS/cm]	110	2,400	< 1,500
pH	[\]	6.4	7.9	7.0 – 9.5
Ptot	[mg/l]	0.23	0.34	0.2
NH4	[mg/l]	0.5	2.3	0.3
NO3	[mg/l]	0.0	16.0	*[3]
Cd	[µg/l]	0.3	13.0	< 1.0
Zn	[µg/l]	120	2,000	< 500
Cu	[µg/l]	97	104	< 50
Pb	[µg/l]	11	525	< 25
Ni	[µg/l]	4	70	< 20
Cr	[µg/l]	6	50	< 50
PAH	[µg/l]	0.2	17.1	< 0.2
TPH	[mg/l]	0.1	6.5	< 0.2

The sludge trap, depending on the size and expected pollution load of the connected area is designed that it can be absorb the solid loads of about 2 years. After that the sludge collection chamber must be sucked out [Feldhaus, R.; et al., no year; Annex 3].

The maintenance intervals of the filter element can be specified with 2 years. The filter element can be backwashed or replaced easily with the removal tool [Feldhaus, R.; et al., no year; Annex 3].

4.5.3 Surface drain filter with BIOFIL substrate

The Surface drain filter with BIOFIL substrate is made by the company Heitker Ltd. can be used for the treatment of stormwater of traffic areas followed by percolation [Feldhaus, R.; et al., no year; Annex 3].

The surface drain filter consists of 120 cm long, 40 cm wide and 20 cm high elements made of polypropylene (PP), which are filled with the filter substrate BIOFIL. The filter substrate BIOFIL is a mixture of natural mineral stones of various types of development and origins with various additives. Depending on the application additives of iron-containing minerals or organic carbon sources are added [Feldhaus, R.; et al., no year; Annex 3].

The surface drain filter can be used as an individual box, as a larger area or as a trough filter either with or without grating cover (polypropylene (PP) or steel) [Feldhaus, R.; et al., no year; Annex 3].

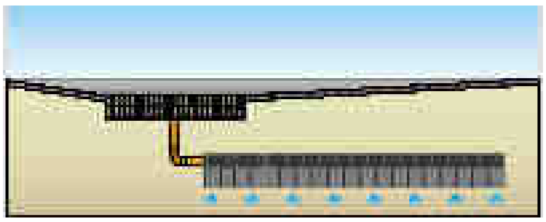

Figure 33 Construction surface drain filter with percolation blocks [Heitker Ltd., 2007]

The water flows through the surface drain filter with BIOFIL-substrate. The permeability of the substrate is up to k_f = 10 – 2 m/s. At the substrate a treatment of the stormwater by physical-chemical-biological mechanism action of takes place. After the treatment, the stormwater percolates through an underground percolation system into the subsoil [Feldhaus, R.; et al., no year; Annex 3].

Final results of tests and investigations of the BIOFIL-substrate are not yet available. The substrate is being subjected to various laboratory tests. Based on the current information the company Heitker Ltd. gives the following efficiencies [Feldhaus, R.; et al., no year; Annex 3]:

Table 26 Cleaning efficiency of the surface drain filter with BIOFIL substrate [Heitker Ltd., 2007]

Parameter	Efficiency [%]
TSS	80 – 99
COD	70 – 95
P_{tot}	60 – 80
NH_4	60 – 99
Heavy metals	up to 98
PAH	80 – 99

5 Best Practice

"Best practices are generally-accepted, informally-standardized techniques, methods or processes that have proven themselves over time to accomplish given tasks." [Wikipedia: Best practice, URL; 07/06/2011]

In order to determine the best practices for stormwater management of road stormwater runoff, the basic situation must be found. The current situation in the individual states is part of that. It will examine what procedures are primarily used and for what reason. Also, any developments or a change in the practices used in recent years is considered. Only then a comparison of the practices can be done, which can lead to a preference for one procedure.

5.1 The situation in the federal states

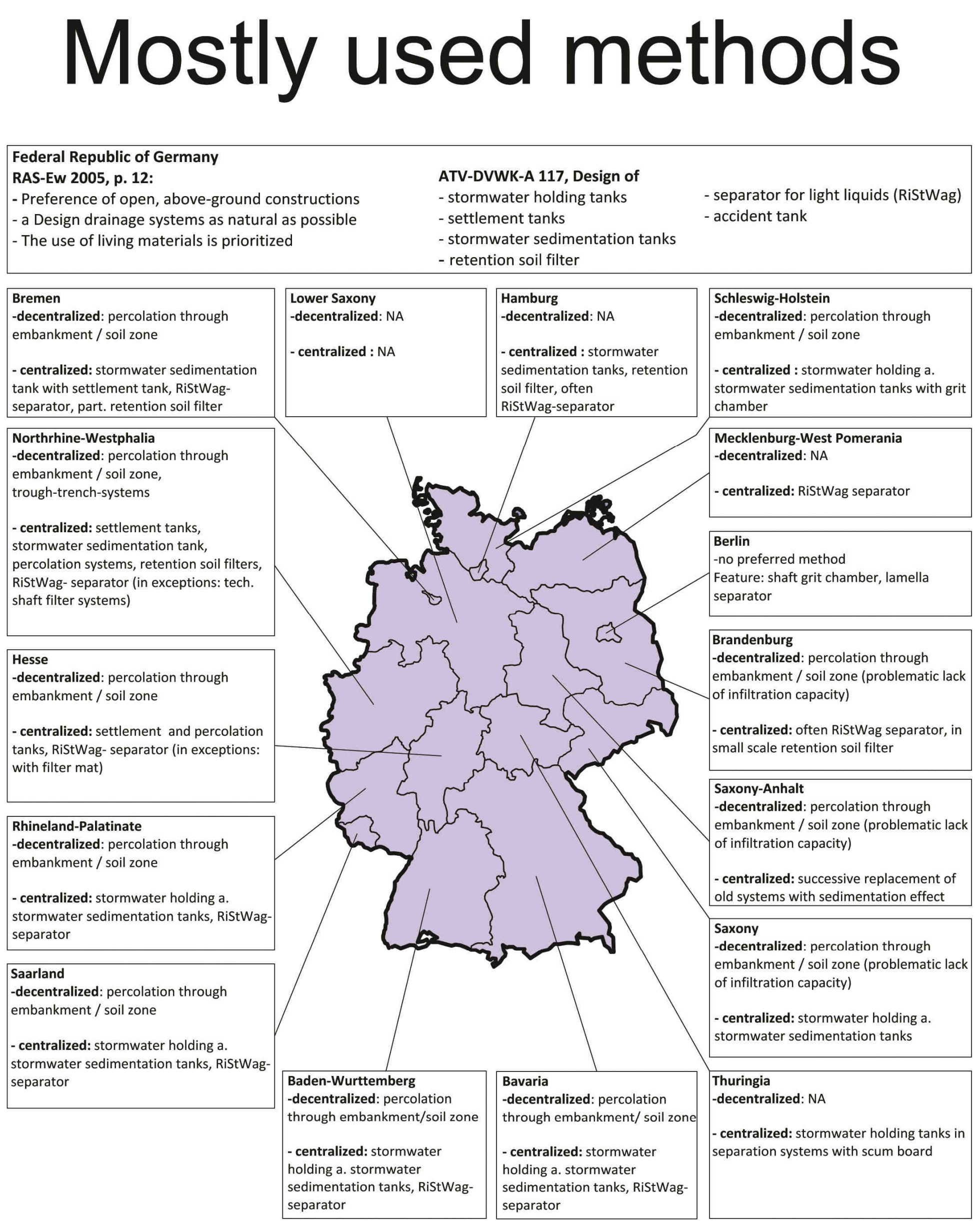

Figure 34 Overview of the mostly used methods for the treatment of stormwater of highways in the federals states

Berlin, with a settlement and traffic area of approx. 70 % is a highly urbanized state [Statistics Office Berlin-Brandenburg, 2010; p. 28].

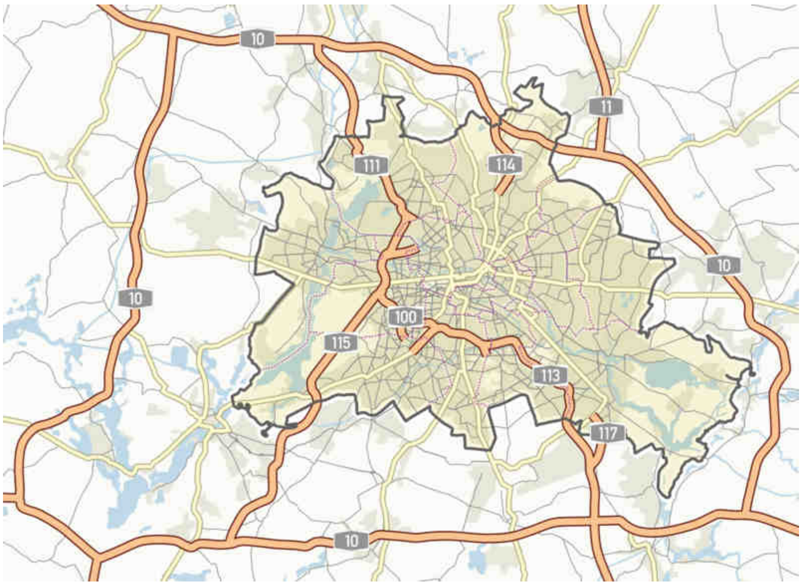

Figure 35 Berlin Road Map [Wikipedia: Berlin, URL; 07/17/2011]

Therefore other basic requirements for deciding exist, which method is used. Berlin prefers no specific treatment procedures because of its very diverse area characteristics. There are used shaft grit chambers, lamella separator as well as retention soil filters and in the near future high performance sedimentation systems. When building new roads all points of discharge of road gullies are mostly equipped with retention soil filters. In addition, Berlin has found that a regular cleaning of the sludge baskets in the road gullies proved to be an essential factor in the treatment of surface water of roads. This cleaning is done by the Berlin city cleaning [Buge, F.-M., 2011; e-mail].

Brandenburg in comparison is a much larger state, and thus also has a highly differentiated landscape. Here, the settlement and traffic area account for just 10 % of the total area.

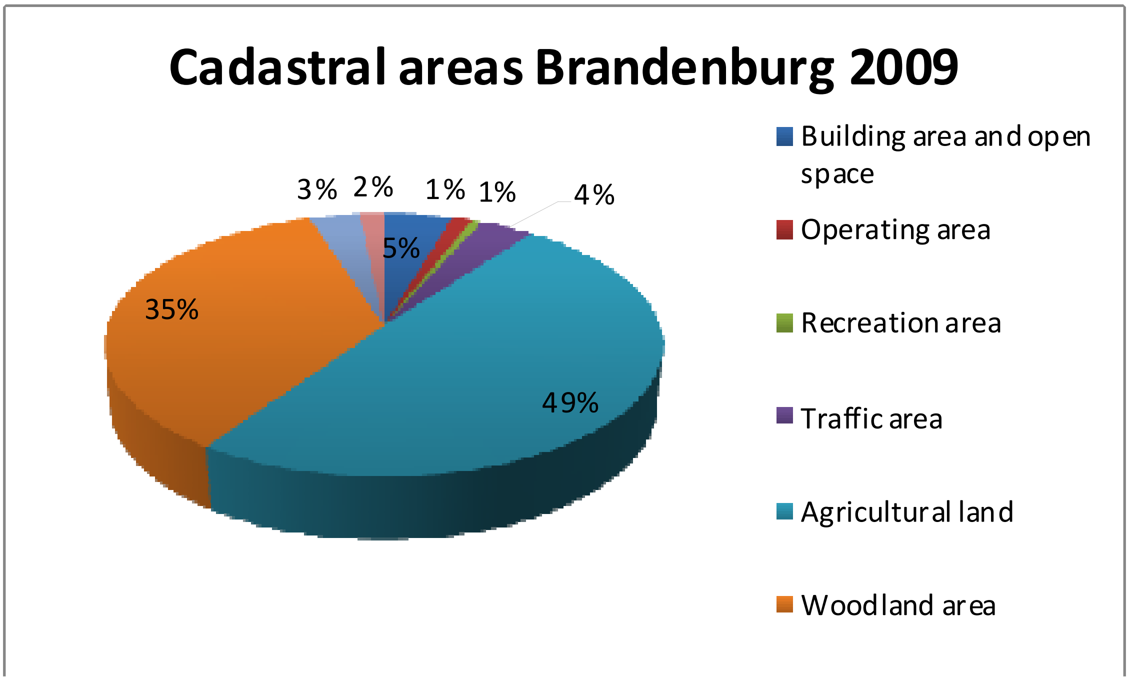

Figure 36 Cadastral areas of Brandenburg of the year 2009 [Statistics Office Berlin-Brandenburg, 2010]

Especially in many parts of Brandenburg agriculture make up a large part of the area [Statistics Office Berlin-Brandenburg, 2010], as shown in Figure 37.

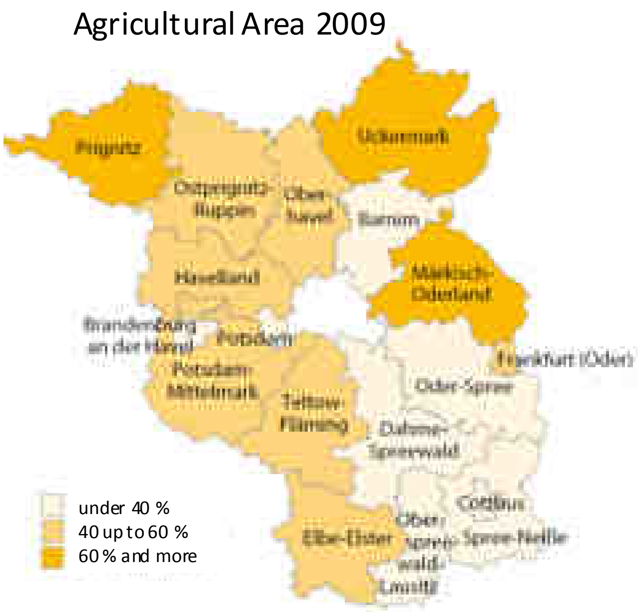

Figure 37 Use of the land area as agricultural land in 2009[Statistics Office Berlin-Brandenburg, 2010]

Because of their efficiency in the central system, retention soil filters are favored. This decision depends on the specific costs that are determined, for example by the costs per eliminated phosphorous. Due to the technical regulations conventional RiStWag- separator still dominate, so that the number of retention soil filter systems is still comparatively low. In the decentralized sector the percolation through the topsoil zone dominates, which benefits from the prevailing morphology and the common soil conditions [Merten, Oliver Dr., 2011; e-mail].

In **Saxony-Anhalt** similar circumstances as in Brandenburg prevail. Here too, the proportion of the settlement and traffic area is about 10 % [Statistical Office of Saxony-Anhalt, URL; 07/17/2011]. As a treatment method for road runoff open systems with cleaning effect of the vegetated soil zone are applied. This applies both at the central and the decentralized treatment. The treatment systems with pure sedimentation effect built in the past will be rebuilt into vegetated soil filters with grass corps after the end of its useful life or for early rehabilitation needs [Buschmann, B., 2011; e-mail]. Settlement and stormwater sedimentation tanks are built only in exceptional cases [Borchert, G., 2011; e-mail].

In Saxony and Thuringia usually soil filters are not used. In **Saxony**, this is mainly due to the insufficient infiltration capacity of the soil, so that any decentralized methods are usually not feasible. There, mostly stormwater holding tanks with upstream stormwater sedimentation tanks are used. **Thuringia** tries not to take stormwater and to achieve a percolation through the bench. If this is not possible, the cleaning is similar to Saxony.

Northrhine-Westphalia is the most populated state, with 34,080 km² only the fourth largest state of the Federal Republic of Germany. The center and south of the state are area heavily urbanized due to the Rhine-Ruhr; the north is on the other hand essentially rural. Therefore the percentage of the traffic area of the total area of the state of about 7 % is relatively high [Information and Technology NRW (ed.), 2010; p. 38 et seq.].

In Northrhine-Westphalia according to the circular “Drainage Engineering measures on federal highways and country roads” [MBV-NRW a. MUNLV-NRW, 2010] the local percolation of road surface water from outside the continuous built-up areas through the biological active soil zone with no upstream connection of stormwater treatment systems are the rule and have top priority. This principle must be ensured by an adequate protection an appropriate groundwater cover

[MBV-NRW a. MUNLV-NRW, 2010; numeral 2]. If no percolation from the road surface water is possible, due to environmental conditions, the water is to be hold and derive. For treatment, retention and diversion of the water separators for light liquids, settlement tanks or settlement systems, stormwater sedimentation tanks, different percolation systems or retention soil filters are used. Here, usually combination systems in form of stormwater holding systems in combination with settlement tanks, light liquid separators, stormwater sedimentation tanks, soil filter systems or percolation systems are used. The selection will be coordinated between the relevant traffic and environmental protection authorities.

Schleswig-Holstein is the northernmost state of the Republic and strongly influenced by agriculture. With regard to the importance of agriculture in Schleswig-Holstein it becomes clear why the large amount of 70% of the land is used for this purpose. (Figure 38). In contrast, the percentage of traffic area of the total area of 4.4 % compared to other states is low [Statistical Office of Hamburg and Schleswig-Holstein (ed.), 2011].

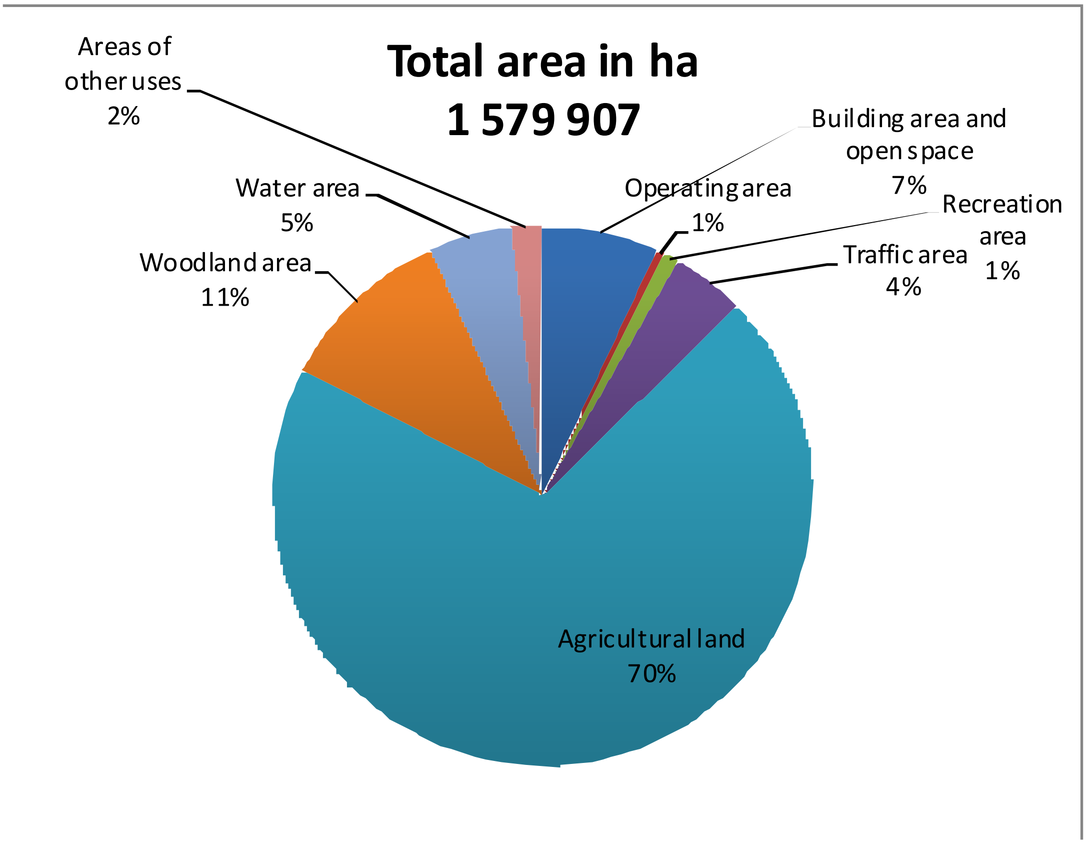

Figure 38 Use of the land in Schleswig-Holstein of 12/31/2008 [Statistical Office of Hamburg and Schleswig-Holstein (ed.), 2011; p. 263]

According to the “Technical regulations for construction and operation of facilities for stormwater treatment in separate sewer system” [MLUR SH, 1992] in Schleswig-Holstein, the stormwater principally has to be treated prior to its discharge. For the treatment of stormwater stormwater holding tanks, light liquid separators, stormwater sedimentation tanks, vortex separators, vegetation passages, spill filter and pond systems are possible options [MLUR SH, 1992; numeral 1 and 2.4]. In the semi-centralized treatment of road runoff mainly stormwater holding tanks or stormwater sedimentation tanks with upstream grit chamber according to RAS-Ew are used. However, a decentralized treatment or road surface water via troughs, ditches and vegetation passages is generally preferred. Key criteria for selecting the method are the resulting water quantity, the water quality, the type of road and the distance to the discharge point.

The area of the city-state of **Hamburg** is predominantly urban. With about 1.8 million inhabitants in an area of 755.3 km² Hamburg has, compared to other major German cities, a relatively low population density of 2,348 inhabitants / km². This is mainly due to the port areas and larger rural areas, where only few people live. The percentage of traffic areas of the total area of Hamburg lies at 12.1 % (see Figure 39). In addition to the traffic areas are also areas for rail, air and waterway transport counted [Statistical Office of Hamburg and Schleswig-Holstein (ed.), 2011; p. 14, 236].

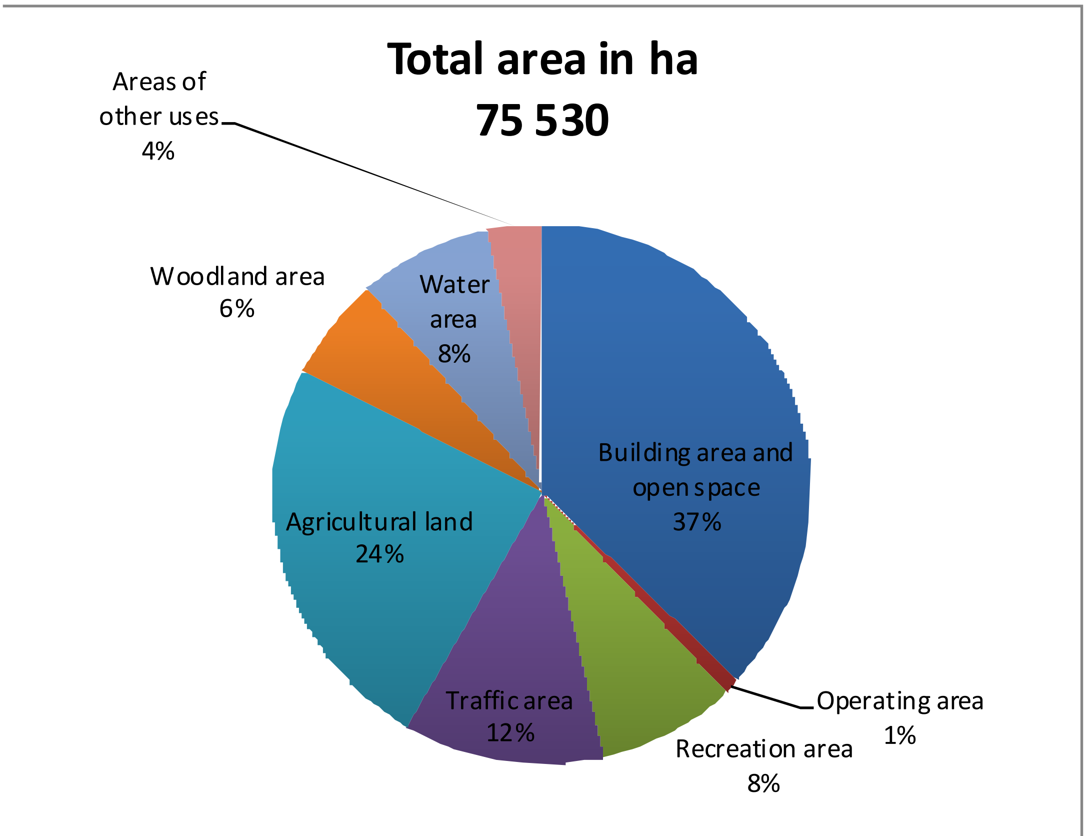

Figure 39 Use of the land in Hamburg at 12/31/2008 [Statistical Office of Hamburg and Schleswig-Holstein (ed.), 2011; p. 239]

Eligible for central treatment of road surface water in the city state of Hamburg, both physical and biological processes are applied. Grit chambers, pond systems, light liquid separators, stormwater sedimentation tanks, compact sedimentation systems and filtration systems are used. If possible, retention soil filters should be used in these systems. In the decentralized sector in Hamburg, few experiences have been made and few standards have been set.

Baden-Wurttemberg is the third largest German federal state and is with its approximately 10.7 million inhabitants in third place. The in the southwest located state shares borders with three German states (Bavaria, Hesse and Rhineland-Palatinate) and three European countries (Austria, Switzerland, France). The area distribution is generally more heterogeneous, with the regions around Stuttgart and Mannheim presenting two large metropolitan areas. Overall, the portions of settlements and traffic areas in the rural areas vary strongly from region to region. In the more rural regions the traffic opening causes a high area requirement. On the other hand, in urban areas outweighs the area requirements for building and open space. From east to west a gradient of settlement and traffic area per inhabitant is also observed. At the common border with Bavaria, the values of the proportion of settlement and traffic area is high, in the Rhine Valley and the region around Stuttgart it is low [STALA-BW, URL; 08/04/2011]; [STALA-BW, URL; 08/05/2011].

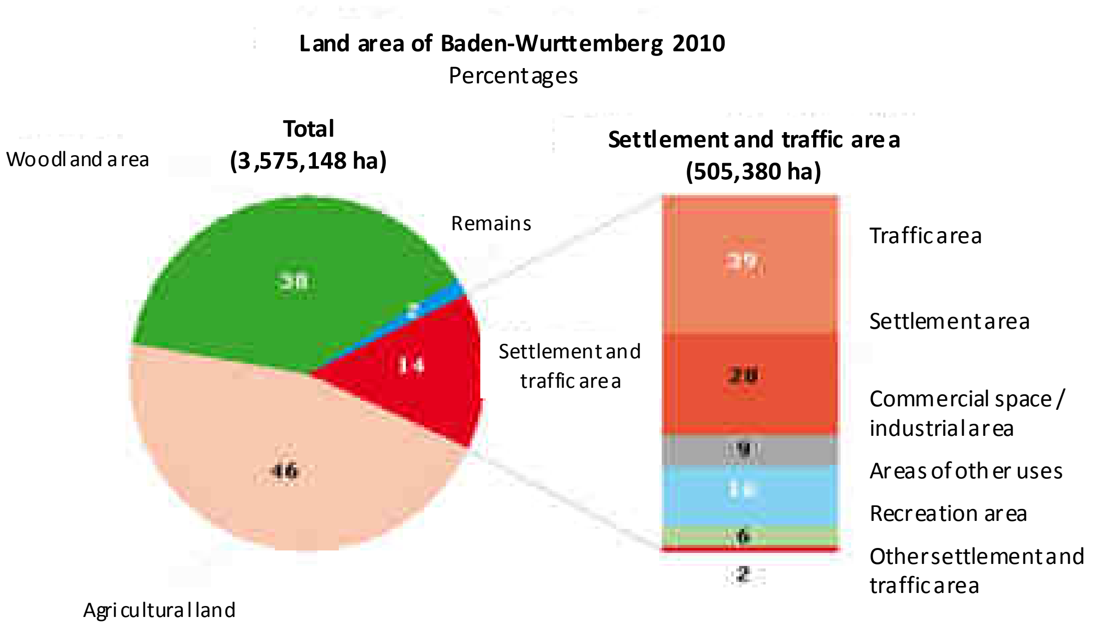

Figure 40 Land area on actual use in 2010 [STALA-BW, URL; 08/04/2011]

The preferred method of treatment for road runoff is, according to the Administrative Regulation on the removal of road surface water [IMBW a. UMBW, 2008-a], the decentralized wide-area percolation through the batter or adjacent to the banquet soil zone. For topographical, geological, soil science, water management or constructive reasons, a wide-area percolation is not possible. In this case, a collection of drainage is provided [IMBW a. UMBW, 2008-a; numeral 3.4.5].

Primarily, stormwater sedimentation tanks and RiStWag separator serve as a central treatment system. With the Administrative Regulation on the treatment of road surface water, the "Technical rules for discharge and treatment of road surface water" [IMBW a. UMBW, 2008-b] has been made compulsory in January 2008.

5.2 Comparison of the methods

Table 27 Evaluation matrix of survey of the federal states to the used methods for cleaning and removal of road runoff

	Treatment Method					
	decentralized		centrally			
State	Percolation through embankment / soil zone	Percolation through embankment / soil zone and trough-trench systems	Stormwater Retention Basins (SRB)	Stormwater Sedimentation Tank (SST) / Settlement Tank	RiStWag-Separator	Retention soil filter (RSF), and other percolation system
Baden-Wurttemberg	X		X	X	X	
Bavaria	X		X	X	X	
Berlin	(x)		(x)	(x)[1]	(x)	
Brandenburg	X		(x)	(x)	X	X(-)
Bremen	X		(x)	X	X	X(-)
Hamburg	X		(x)	X	X[2]	
Hesse	(x)		(x)	X	X(+)	X
Mecklenburg-West Pomerania	(x)		(x)	(x)	X	
Lower Saxony	(x)		(x)	(x)	(x)	
Northrhine-Westphalia	X	X	(x)[3]	X	X	X[4]
Rhineland-Palatinate	X		X	X	X	
Saarland	X		X	X	X	
Saxony	X[5]		X	X	(x)	
Saxony-Anhalt	X		(x)	(x)[6]	(x)	(x)[7]
Schleswig-Holstein	X		X	X[8]	(x)	
Thuringia	(x)		X	(x)	X	
	Explanation: X Method is applied; (x) Method is properly applied; (+) is frequently applied; (-) is rarely applied					

[1] with shaft sand trap and lamella separator
[2] partly with filter mat
[3] with and without permanent storage
[4] also percolation systems and technical shaft filter systems
[5] problematic lack of infiltration capacity of the existing soils
[6] Substitution of old systems with tank systems: with falling dry lawn surface / vertical passage, possibly draining (soil filter)
[7] see note 6
[8] with grit chamber

By most states, the decentralized percolation trough the batter or the topsoil zone was cited as a prioritized method. For the states, that do not mention this method explicitly, it can still be assumed for these states. This follows from the principle stated in the WHG § 55, that stormwater should be percolated, trickled or initiated over a separate sewer system in waters close to the source, unless water rights, water management regulations or other public interests conflict with it.

In Northrhine-Westphalia trough-trench-systems are also used on roads outside urban areas, as well as in urban areas.

In the central treatment of stormwater runoff from roads stormwater holding tanks, stormwater sedimentation tanks, and RiStWag separators are used. Retention soil filters and other percolation systems are probably the exception. Especially in Northrhine-Westphalia a lot of experiences with this method were gained.

Especially in Berlin, additional equipment for existing tanks, for example, lamella separators or modifications for new buildings are often used. This is due to the limited space within the city, which often enable the construction of a normal-sized stormwater tank.

5.2.1 Comparison parameters

For the selection of a specific method for treatment of road runoff it is critical in the first place, what the safety requirements in a particular place for the protection of water (water protection areas) are. Furthermore, the site conditions can also influence the selection and design of a treatment system (infiltration capacity of soils, further requirements of environmental protection laws: waters, nature and landscape, soil, space and land availability, etc.).

This background information can make the use of a particular method necessary or exclude it completely. A consideration of these priority decision parameters show that certain conditions restrict the choice of possible methods to a number of really applicable methods and make certain demands on the treatment of road runoff.

In the narrow range of methods: either a specific protection requirement and legal provision decides directly on the applied method, or multiple methods are in question in order to fulfill a specific purpose cleaning. In addition to the requirement of protection, legislation and local conditions, other external conditions are incorporate at one in the decision. A great role plays experiences in relation to the state of art and practicality in everyday operation. Moreover, the principle of economic interaction with public funds is to be observed. The actual transfer rate or targeted benefits must be proportionate to the costs.

The explanations presented above to the priority decision parameters set as a first overview of the reasons for the selection of a method.

To make an informed decision for a particular method, the system-specific characteristics are considered. The context of decision-relevant backgrounds, system-specific characteristics and the selection of a method for treatment of runoff are depicted in Figure 41.

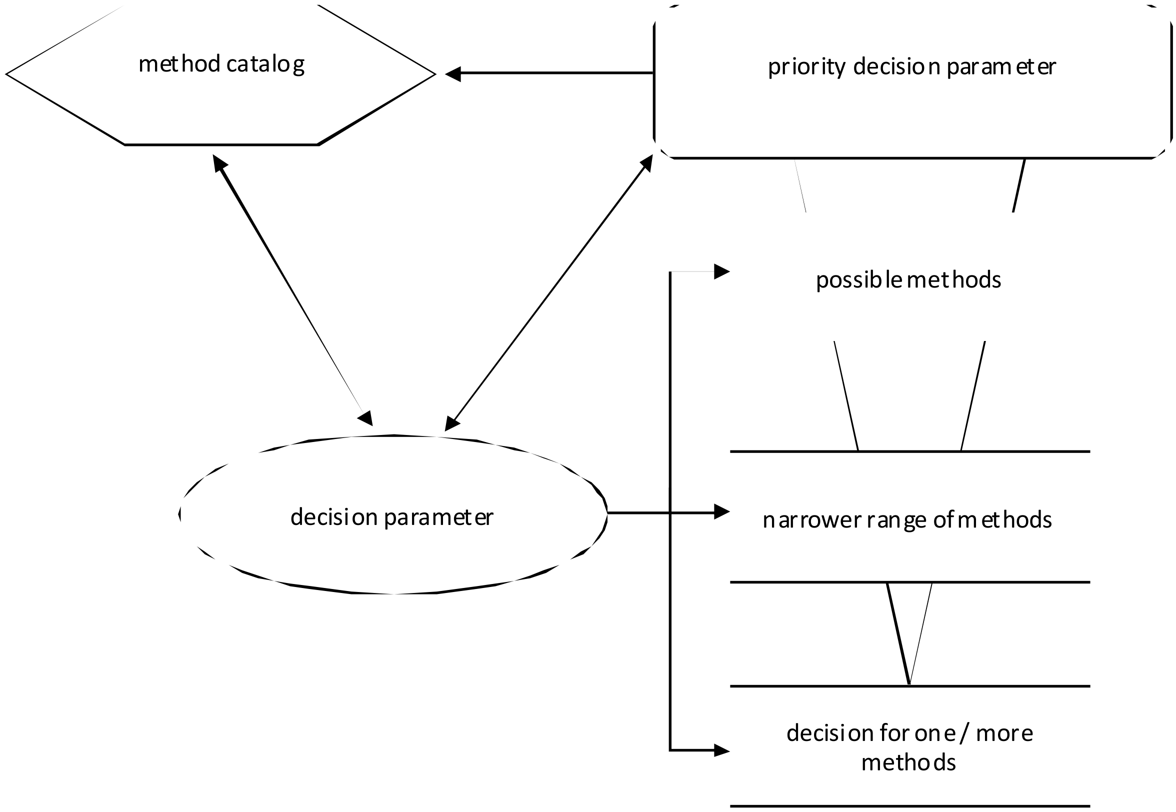

Figure 41 Flow chart for selecting a method [Waltz, N.; Ceko, R., 2011]

Following a description of evaluation parameters that should draw a comprehensive overall picture of the methods listed is given. The evaluation parameters were chosen in such a way, that they allow for the possibly best conclusions in terms of performance and costs.

The described parameters are used to evaluate the various central and decentralized methods. Then the valuation is made in a table. Through the evaluation, each method can be looked at by itself or in comparison to the other methods.

5.2.1.1 Cleaning efficiency (total suspended solids – TSS)

Total suspended solids (TSS) are contained in the wastewater settling sediment, suspended solids and floating matter and are separated by filtration. They usually produce a visible haze. Its content is expressed in mg/l [Wikipedia: TSS, URL; 07/17/2011].

The TSS is an important parameter for the cleaning efficiency because on the one hand the TSS rates bring a high pollution potential with it (see Table 3) and on the other hand, a large percentage of contaminants is bound to these particles (see Table 9).

5.2.1.2 Investment costs

Investment costs are part of in the planning and construction of the treatment system. These can vary greatly by the type of system. Especially the excavation of underground facilities makes up a significant proportion of the investment costs. Therefore the investment costs can be reduced significantly just by decreasing in the tank volumes.

5.2.1.3 Operating costs

The operating costs result from the monetary expenditures for the operation and maintenance of the systems for the retention and treatment of road surface water. For a secure and permanent function of the structures regular and unscheduled inspections and proper maintenance are required [Uhl, M. et al., 2006].

The costs are made up by the money that is spent on variable costs and fixed costs (such as materials, electricity, and wages). The operation and maintenance lies in the responsibility of the road maintenance service.

5.2.1.4 Size ratio

All road surface treatment systems require a certain amount of surface area to clean the stormwater. Also, system development and maintenance devices can increase the space requirements of a system significantly. In order to achieve a particular efficiency, natural methods usually require a larger cleaning area than technical systems. Decentralized treatment methods are distinguished from the central processes with a more compact design, which is why they often must rely o a smaller land, or can even be integrated into other buildings.

5.2.1.5 Landscape

The term landscape refers to the perceptible appearance by human of a scenery. It includes all the effects of perceptible characteristics and properties of nature and scenery on people. The fulfillment outweighs the primary visual impressions, and these may consists of natural and anthropogenic elements. Ultimately, these are perceived subjects, influenced by the character, ethics, education, upbringing and experiences of the people [Federal Minister for Transport (ed.), 1991; p. 14 et seq.]

By the Federal Nature Conservation Act[26] [BNatSchG, 2009] the landscape in accordance with § 1 para 1 no 3 is protected. There it says: Nature and landscape […] are to be protected so that the diversity, uniqueness and beauty and recreational value of nature and landscape are secured in the longer run [BNatSchG, 2009; § 1 para 1]. Further is in § 1 para 5 sentence 3 BNatSchG that roads should be designed in such a landscape including requirements, so that the use of the landscape and a damage the ecosystem can be avoided or minimized. Traffic routes also include decentralized and centralized systems for the treatment of road surface water.

The parameter "landscape" is evaluated positively where the treatment system fit well into the landscape. This also has an effect, whether the systems pose a man-made biotope. Negative aspects are assessed in addition to the design not landscape including requirement, a high degree of sealing and whether the systems are perceived as such immediately.

5.2.1.6 Flow rate (surface load)

The flow rate is measured in volume per time (m^3/s or l/s). As flow rate the amount of water is given, which flows in a certain time through a system [Water-Money-Save, URL; 07/17/2011]. The more water can be treated within a certain time, the more positive the method is evaluated.

5.2.1.7 Maintenance effort

The maintenance of buildings serves the maintenance of the viability and is an integral part of the entertainment activities. Depending on the type of system maintenance costs can differ greatly. Natural processes need in comparison to chemical-physical and technical-mechanical processes less maintenance. Regular in-

[26] Bundesnaturschutzgesetz

spections and maintenance action (visual inspection, banquet peeling, etc.) must also be conducted in decentralized solutions. Decentralized methods have the advantage to centralized solutions that here the runoffs do not have to be fed and so an additional maintenance of pipes (channels, sewage) is not necessary.

Central processes can also differ greatly among themselves in maintenance. Decisive here are the size and physical fabric of the system. They can often fulfill a particular need for protection.

Any defects, damages or seal settlements according to ability or urgency must also be removed immediately to make sure the protective effect [Uhl, M. et al., 2006].

5.2.2 Tabular comparison

A comparison of the flow rate was difficult. The comparison of this parameter should help identify the quantitative performance of each method. But no comparable values were found. Only values about the loading in m/s or m/h were found in the course of processing time. This, however, gives only the inflow rate and makes no statement about the amount treated in a certain period of time. Better will be values in l/s, which would specify how much road runoff can be treated. Another way to find information on the flow rate would be an indication of the max. connectable area per m² of system size.

Table 28 Comparison of the central treatment methods for road runoff

	Central methods						
Parameter	Stormwater sedimentation tank	Retention soil filter	Sand filter	Precipitation / Flocculation			Lamella separator
Cleaning efficiency (TSS)	o / + medium to high	+ high	+ + very high	Sedimentation: o medium	Filtration: + high	Flotation: o / + medium to high	o medium
Investment costs	o medium	- high	o medium	o medium			+ low
Operating costs	+ low	+ + very low	- high	o medium			n.n.
Size ratio	- high	- - very high	- high	+ low			o medium
Landscape	- - very high	o / + medium to low	- high	- - very high			- high
Flow rate (surface load)	no comparison possible						
Maintenance effort	o medium	o medium	- high	- high			o medium

The central processes do more than average to poor (see Table 28).

Especially sand filters and precipitation and flocculation with subsequent sedimentation have received mostly negative reviews. The only positive on the sand filter is its good quality in relation to the cleaning performance (TSS). The investment costs are regarded as average. The other parameters are assessed as negative.

In the precipitation and flocculation three different system combinations are considered. The difference lies in the subsequent removal of the macro-flakes. Distinction is in the separation by sedimentation, filtration and flotation. The difference is observed only in the cleaning performance. For the other parameters the subsequent purification step is not observed. The costs, both investment and operating costs, are in the midfield. On the positive side the space requirement can be seen. But the high maintenance effort and the impact on the landscape is very high and therefore assess negative. On the cleaning performance the system followed by sedimentation does average, the system followed by filtration does positive and the system followed by flotation does intervening.

The stormwater sedimentation tank is assessed intermingled. The operating costs and to a lesser extent the cleaning performance can be seen positively. The space requirement is high and due to the concrete design and enormous size, the impact on the landscape is assessed very negatively. Investment costs and maintenance are in midfield.

The retention soil filter is evaluated per se relatively well. Positive are the cleaning performance, the really low operating costs and the actual low impact on the landscape. But the investment costs are high and the retention soil filter entail an enormous space requirement.

The lamella separator has cut off most positive, but is only partly directly comparable because it serves only as optional extra equipment and not as an independent cleaning method. The investment costs for the pure lamella separator are low. Only negative is the impact on the landscape because of its use in stormwater sedimentation tanks. The other parameters are in the midfield.

Table 29 Comparison of the decentralized methods for road runoff

	Decentralized methods				
Parameter	**Percolation through batter / soil zone, gutters, road gullies, road troughs, drainage ditches (including bar screens / culverts)**	**Percolation through troughs / ditches (percolation troughs / ditches / basins)**	**Centrifoel Safety Road Gulley**	**RAUSIKKO HydroClean**	**Surface drain filter with BIOFIL substrate**
Cleaning efficiency (TSS)	+ + very high	+ high	+ + very high	+ + very high	+ + very high
Investment costs	+ + very low	o medium	+ low	o medium	+ low
Operating costs	+ low	o medium	n.n.	n.n.	n.n.
Size ratio	+ + very low	+ low	+ + very low	+ low	+ low
Landscape	+ + very low	+ + very low	+ low	+ low	+ low
Flow rate (surface load)	no comparison possible				
maintenance effort	+ low	+ low	+ low	+ + very low	n.n.

On the other hand, the decentralized methods perform very positively, but even here there are differences. There is no method in one of the parameters evaluate negatively (see Table 29).

The three methods for treating highly polluted stormwater are close together in the evaluation. The cleaning performance is very high at all three. For the other parameters, there are slight differences, but points out none of the methods.

The percolation through troughs and/or trenches has very little impact on the landscape. In addition, the cleaning efficiency, the space requirements and the maintenance effort are evaluated positively.

It should be noted that the percolation through troughs and/or trenches, as well as the surface drain filter with BIOFIL substrate rarely used in rural areas, but rather finds use in the urban area.

Percolation through the batter is rated most positively. Here all parameters, except for operating costs and maintenance effort, which are rated as good, are assessed very well.

5.2.3 Evaluation of the comparison

The tabular comparison and the textual analysis have shown that the requirements in the nationwide and state-specific regulations to a primary percolation through the batter can be supported by the extremely positive performance of this method in the direct comparison. This method of percolation has performed well to very good in all points and is thus the preferable method.

Furthermore, the comparison shows that technical solutions, such as classic stormwater sedimentation tanks or similar are no longer in a timely manner. They have a huge space requirement and fit poorly into the landscape. Due to their enormous size, they are also economically often not the ideal solution. By combining with lamella separators or other auxiliary equipment it can be saved not only a significant portion of volume and thus on costs, but also the cleaning power can be increased significantly. The use of natural constructions, rather than pure concrete constructions, allow that the use of stormwater sedimentation tanks will be more attractive again.

Retention soil filters are used now more sparingly. Reasons may be the enormous space requirement and the very high investment costs. Nevertheless, the uses of soil filters into a long term are an alternative to stormwater sedimentation tanks. They fit well into the landscape, despite its enormous size, by their close to the nature design and thus have a wide acceptance in the population. Especially at the retention soil filter is still a considerable need for research and is therefore a treatment method, which in future can still play a big role.

Where space is restricted, such as city-states like Berlin or Hamburg, the use of such large methods is often not feasible. Here additional elements that reduce the size of stormwater sedimentation tanks or inserts for shafts, as in the treatment of heavily polluted road runoff are rather common. They take up little space, have good cleaning performance and can often be retrofitted. Importantly, there is a regular maintenance and cleaning to obtain the cleaning efficiency.

Precipitation and flocculation are used more for specific solutions, in industrial parks for example, and are alone because of the huge maintenance effort rather cumbersome in the non-urban use.

6 Monitoring

The term "monitoring" is an umbrella term for all types of observation of intersubjectively perceptible system states over time. "Environmental monitoring" is used when these perceptions are aimed at the scientific documentation or official monitoring of the environment [Marschner, S., 2008].

In Germany, several scientific studies on the advent of pollutants in the road runoff and on the cleaning performance of treatment structures are available. The advent of pollutants in the streets and the effectiveness of percolation measures for the retention of contaminants have been studied frequently in the past ten years[27]. Similarly, results about centralized treatment systems such as drainage basins [Lange, G.; et al., 2001] or retention soil filters[Kasting, U.; Grotehusmann, 2009] are available.

Due to the requirements of the WFD, first assessments of pollutants from road runoff have already been made[Schmitt, T.G.; Welker, A., 2006]; [Stachel; et al., 2007]. The occurrence and behavior of "new" priority substances of the WFD in road runoffs should be explored more in the future [Kocher, B., 2011].

In the survey of environmental and road construction authorities of the states no specific overall monitoring programs for the advent of pollutants can be determined (see Figure 42).

[27] [Beer, F.; Kocher, B., 2010]; [Boller, M; et al., 2005]; [Dierkes, C.; Geiger W.F., 1999]; [Kocher, B., 2008]; [Kocher, B., 2006 & 2007]; [Kocher, B.; Wessolek, G., 2003]; [Lambrecht, B.; Fuchs, S., 2008]; [Nadler, A.; Meißner, E., 2001]

MONITORING

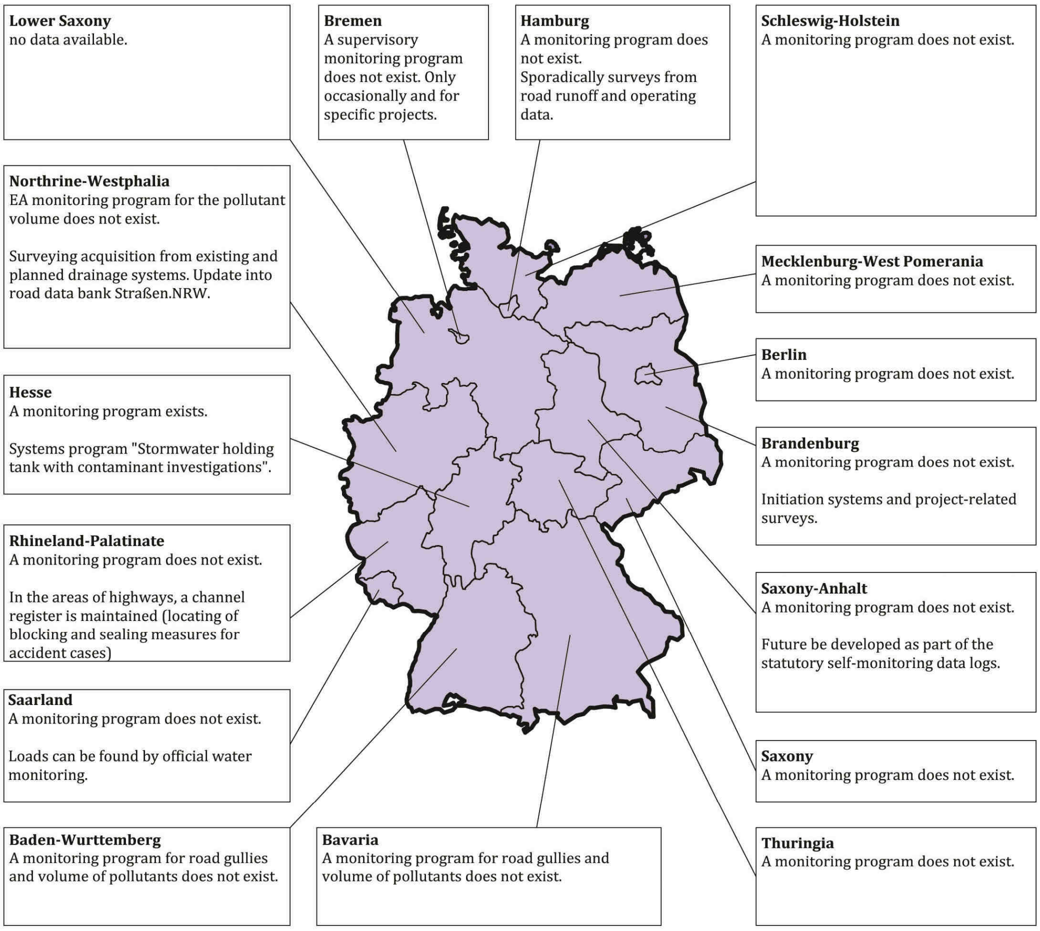

Figure 42 Monitoring programs of the federal states

In some states, sporadic studies on road runoffs and operating data of the treatment systems are available. In Hesse, an investment program on stormwater holding tanks with pollutant investigations was conducted. After which the stormwater holding tanks were rebuild and adapted to modern standards[28].

Deposits and age-related wear in the drainage facilities and other stresses of the inlet points can affect the functioning of the drainage systems and make regular checks necessary. The Federal Water Act regulates under § 61 (1), that the estab-

[28] written notice of the Hessian State Office for Road and Transport (HSVV)

lishment and operation of drainage facilities must comply with the generally accepted rules of the art.

From authorities, the road maintenance service[29] leads all maintenance activities[30] (maintenance, care and control) at the streets and their operating relevant facilities.

This year the FGSV has issued “Guidance about control and maintenance of drainage systems (collection, discharge, retention and treatment of road surface water” on roads outside urban areas” [FGSV, 2011]. Unless the states have not even introduced legal regulations in the self-monitoring and self-control regulations (WHG § 62), the evidences for drainage systems will be used[FGSV, 2011; p. 5].

This guidance includes the operational aspects that serve to the warranty, the long-term viability and the prevention of adverse environmental effects. They do not apply for tests related to accidents and disasters [FGSV, 2011].

In case of accidents and disasters measures to protect waters must be carried out quickly. A (digital) sewer register can be useful to take such measures quick and appropriate. The self-monitoring regulations also contain deadlines, until when the sewers must be checked and restored. Thus, systematic recordings of the sewer network are necessary[31].

Rhineland-Palatinate leads a sewer register for the field of highways, in order to locate isolate and sealing measures in accident cases. Northrhine-Westphalia is currently running a surveying capturing of planned and existing drainage systems. The collected data are entered into a road database, which is operating by the State Office of road construction. Probably the road maintenance services of all states also have at least similar performed maintenance history, that form the ba-

[29] For federal highways the highway maintenance and for country, state and federal roads the road maintenance

[30] Immediate measures on the road structure (building maintenance), street cleaning, maintenance of green area including the environmentally friendly recovery of the resulting cut material as well as the maintenance and upkeep of street furniture

[31] In Hesse currently the development of a nationwide sewer register is done; oral. release dated 06/16/2011 of the Hessian State Office for Roads and Transport (HSSV)

sis for an inventory database with which inspection activities and restoration measures can be planned systematically [FGSV, 2011]. It also could occur planning measures for accident and emergency events on the inventory database.

7 Summary, final discussion and outlook

Topic of this thesis was a summary of the legal situation in federal the states of the Republic of Germany, whose current status in the treatment from road surface water and in the monitoring, and the presentation and evaluation of road surface water treatment methods.

In chapter 2 the basics of the drainage of roads have been described. Thereby has been addressed on the German traffic network, as also on the composition of the road surface water and their content. It has been found out that just the TSS presents a significant pollution potential (see Table 3). Furthermore, it was determined that there is a connection between traffic volume (DTV) and degree of contamination of the road surface water (see Table 5), but there are other parameters in road traffic, which have an influence on the degree of pollution (see Table 6). It also plays a role in how far the traffic flow is disrupted by braking- and acceleration processes, which can lead to an increased emission of heavy metals. Possible criteria for assessing such disorders of the traffic can be for example the number of crossings with or without traffic lights, the number of pedestrian crossings and the parking possibilities along a street. Similarly, an increased risk of congestion leads to higher pollutant concentrations. Heavy metals are usually bound to articles with a size < 0.6 and < 1mm. These portions are usually easy to remove by filtration. Copper, however, is to percolate well and thus represents a risk to waters. A reduction of copper in the brake pads could reduce the concentration of copper in road surface water. PAH and TPH are also predominantly particulate bound and thus to remove well. Other organic pollutants must be examined more closely because of the WFD. About cleaning options is so far little known. In order to embrace the water right requirements possible adjustments at the state of the art will be necessary. A still standing problem is the chloride load from road runoff through the use of road salt. So far, no satisfactory cleaning can be achieved.

In the next section (chapter 3), the legal situation of road drainage in the EU (chapter 3.1), the Federal Republic of Germany (chapter 3.2) and in the individual federal states (chapter 3.3) was shown. It has been shown that up to now there are no legal target values and requirements for the discharge of stormwater and road surface runoff into the groundwater or surface waters. It will be used only in alternative the test value of the BBodSchV. These values can only be regarded as temporary solution because, although such a large proportion of pollutants from road runoff, but the pollutants in its entirety cannot be judged. Also in the Waste-water Ordinance (chapter 3.2.2) no annex on stormwater is available, but is in development. By the proposed annex in the future requirements on the condition and how to deal with stormwater should be regulated federally. It is hoped that the drafting of the annex can be completed promptly, despite quiescent the process. Furthermore, it was noted that for the discharge of stormwater into the groundwater through a harmless percolation a water right permit is necessary. The RAS-Ew, which is supplemented by the DWA-M 153, the DWA-A 138 and the BWK M-3, shows, that a percolation over the batter or grass trough is desirable (chapter 3.4.2.1). The research on the legal situation in the states (Figure 7) has made it clear, that the states vary widely in dealing with road surface water. States, in particular Northrhine-Westphalia and Baden-Wurttemberg, make a lot in this field, research, investigate and regulate progressive. In other states, however, with the exception of the state-owned water acts it has been no legal dispute with road runoff so far. In addition, a very meager return of some state offices was noted. To Lower Saxony no contact was possible. Since the amendment of the WHG the general requirement level for the discharge of sewage has been the “prior art” (§ 7a WHG). Thus a development of technically and economically viable advanced processes, facilities or modes of operation is required. Under the new principle of the WHG, the federal government is authorized to enforce requirements that corresponded to the prior art, by ordinance. The Waste Water Ordinance provides the emission-related requirements on the prior art, as already mentioned, still endure for the range of precipitation. Also with regard to the variety of technical and legal provisions would be a uniform system-related regulation to the prior art at the federal level would be desirable. The present numerous technical regulations of professional associations and some of which present legal regulations of the federal states and the Federal Republic would have to be compared and brought together. Anyway, the partial required prior art with the advanced scientific insights will continue to develop. With such considerations it should be noted, that state-specific features are to consider. It would also be clarified to what extend in the states and especially in individual cases freedom of action are should given. Topographical, geological, pedological, water management or design reasons, which can vary regionally and locally, demand correspondingly adapted solutions. Some leeway, as well as bringing together existing regulations could increase the applicability.

The next chapter (chapter 4) dealt generally with the current state of the art. Therefore the most common methods from different fields were presented. There mechanical methods (chapter 4.1), treatment by filtration (chapter 4.2), chemical and physical treatment (chapter 4.3), nature-orientated methods (chapter 4.4) and special methods for the treatment of heavily polluted street surface water (chapter 4.5) are shown.

Result of Chapter 5 was a diagram of the most common methods in the states (Figure 34). Therefore information about the methods used mainly in the states, the reasons and possible specifics were collected. Here the return of information was even significantly lower than in the legal part. The results of this chapter are therefore not seen as conclusive, but should provide guidance for further surveys in this area. Again, there were some differences in the states. Berlin, for example, as a city-state and very urban-oriented state uses many alternatives to traditional treatment methods, because simply usually there is not the place for a regular stormwater sedimentation tank or retention soil filters everywhere available. North-rhine-Westphalia, however, is not only in the legal sense the other states one step ahead. There are many research studies to drive the optimization of the classical methods and the development and establishment of new methods. This comparison of states shows that the choice of method depends not only on the current state of art. There are many other factors that have an influence on decision making. It begins with the composition of the road runoff. Depending on how high the load is and with which substances the road surface water is contaminated, different methods are used. Furthermore, it is of course important, what level of cleaning should be achieved. So how should the outlet values should be. Another important factor in the choice of method is the location. Not everywhere for example a soil filter due to the prevailing soil conditions is possible. Also the cleaning of road runoff within a water protection area can restrict to a few of the cleaning methods. The existing space and the fitting of the system into the landscape are location factors which must be observed. Another very important factor, especially for the authorities is the costs. These include firstly the investment costs, which mean the costs of planning and construction of the system, as well as operating costs, which are responsible for the maintenance of the system. These include, depending on the method, cleaning costs, maintenance costs, costs for eventual energy use and depreciation costs. Therefore, it was also tried to observe these factors in the following comparison of methods (chapter 5.2). Here, the most common methods and some special methods were compared. It was divided into centralized (Table 28) and decentralized (Table 29) systems. This comparison has shown that the decentralized methods have generally done better than the centralized. In particular, the percolation trough the batter has stood out positively. This is consistent with the requirements of a preferred percolation through the batter in the regulations, if a further treatment is not necessary. Furthermore, the comparison shows that the technical methods, particularly the stormwater sedimentation tank is no longer seen as the standard solution. Especially natural methods, such as retention soil filters are a good alternative with many advantages. But is has been found during the search, that in terms of plant and filter substrate choice still is need for research and the retention soil filters are in their development not complete yet.

In chapter 6, the monitoring has been discussed. First the terminology has been discussed. Then the situation or the state of development in the individual federal states was considered. It has been shown that especially in the field of monitoring from a majority of states no developments can be reported. Often, only project- or system-specific monitoring is carried out. In some states, like Hesse, sewer registers are planned which can entail a monitoring program. Finally, it is to say, that in the field of monitoring by the states is still a lot to do, because of it is a prerequisite for an effective operation of the sewer system and the related facilities.

Finally, it should be noted that the states in all three fields, law, applied treatment methods and monitoring, are differently developed. It must be stated that in general is still a need for development work. Furthermore, it can be noted that no methods shall be assessed as the best, but the choice of treatment method depends on various factors, as described above and with each new project must be decided anew.

8 Bibliography

AbwAG [2005]: *Act concerning charges for the discharge of wastewater into waters* (=Gesetz über Abgaben für das Einleiten von Abwasser in Gewässer - Abwasserabgabensetz) in the version of announcement of 18 January 2010; Federal Law Gazette p. 114; last amended by Article 1 of the Act of 11 August 2010, Federal Law Gazette p. 1163.

AbwV [2004]: *Regulation on requirements for the discharge of wastewater into waters* (=Verordnung über Anforderungen an das Einleiten von Abwasser in Gewässer - Abwasserverordnung) in the version of announcement of 17 June 2004 Federal Law Gazette p. 1108, 2625; last amended by Article 20 of the Act of 31 July 2009, Federal Law Gazette p. 2585.

ASTRA a. BAFU (ed.) [2010]: *Street Wastewater Treatment Processes.* State of the Art. Issue 2010, V1.00, Bern.

ATV-A 128E [1992]: *ATV-Work Sheet A 128E: Standards for the the Dimensioning and Design of Stormwater Structures in Combined Sewers.* ATV Wastewater Treatment Association.

ATV-A 166 [1999]: *ATV-Work Sheet A 166: Buildings of the central stormwater treatment and retention* (= Bauwerke der zentralen Regenwasserbehandlung und -rückhaltung). ATV Wastewater Treatment Association.

ATV-DVWK-A 117E [2006]: *Dimensioning of Stormwater Holding Facilities.* DWA German Association for Water Management, Sewage and Waste.

ATV-DVWK-M 153E [2000]: *Recommendations for action for handling with stormwater.* DWA German Association for Water Management, Sewage and Waste.

ATV-DVWK-M 176 [2001]: *Instructions and Examples of structural design and equipment of buildings of the central stormwater treatment and retention* (=Hinweise und Beispiele zur konstruktiven Gestaltung und Ausrüstung von Bauwerken der zentralen Regenwasserbehandlung und -rückhaltung). DWA German Association for Water Management, Sewage and Waste.

BauGB [2004]: *Town and Country Planning Code* (= Baugesetzbuch - BauGB).

BayWG [2010]: *Bavarian Water Act* (=Bayrisches Wassergesetz - BayWG) of 25 February 2010 (Law Gazette p. 66, p. 130, Bavarian Laws 753-1-UG).

BbgWg [2004]: *Brandenburg Water Act* (=Brandeburgisches Wassergesetz - BbgWg) in the version of announcement of 8 December 2004 (Law and Ordinance Gazette/05, [No. 05], p. 50), last amended by Article 2 of the Act of 15 July 2010 (Law and Ordinance Gazette/10, [No. 28]).

BBodSchG [1998]: *Law on protection against harmful soil changes and for remediation of contaminated sites* (=Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten - Bundes-Bodenschutzgesetz - BBodSchG) of 17 March 1998, Federal Law Gazette p. 502; last ameded by Article 3 of the Act of 9 December 2004, Federal Law Gazette p. 3214.

BBodSchV [1999]: *Federal Soil Protection and Contaminated Sites Regulation* (=Bundes-Bodenschutz und Altlastenverordnung - BBodSchV) of 2 July 1999, Federal Law Gazette p. 1554, last amended by the Article 16 of the Act of 31 July 2009, Federal Law Gazette p. 2585.

Beer, F.; Kocher, B. [2010]: *Pollutant input in road soils - measuring period 2008/2009.* Research Report of the Federal Highway Research Institute, in publication.

Berlin environment [2001]: *Wastewater Disposal Plan Berlin* with special attention to pollution control target planning. Senate Department for Urban Development, Berlin.

BfN [2010]: *Economic valuation nature-friendly flood control on the Elbe.* Nature Conservation and Biodiversity, Issue 89.

BMVBS [2010]: *Verification of the required plans for the federal railways and federal highways in the version of 11/11/2010.* Federal Ministry of Transport, Building and Urban Affairs (ed.).

BMVBS [2011]: *Federal investment in highways.* Federal Ministry of Transport, Building and Urban Development, Unit L 22, Berlin.

BNatSchG [2009]: *Law on Nature Conservation and Landscape Management* (= Gesetz über Naturschutz und Landschaftspflege - Bundesnaturschutzgesetz) of 29 July 2009, Federal Law Gazette p. 2542.

Boller, M; et al. [2005]: *Banquets of existing roads.* Research commissioned VSS 2001/2002 on request of the Swiss Association of Road and Transportation Experts (VSS), Zurich.

Borchert, G. [2011]: *Re: Road Drainage* of 05/18/2011. State Offcie Building Saxony-Anhalt, e-mail: Gerald.Borchert@lbbau.sachsen-anhalt.de.

BremWG [2011]: *Bremen Water Act* (= Bremisches Wassergesetz - BremWG) of 04/29/2011, Bremen Law Gazette No. 22 p. 262.

Brombach, H. [1997]: *Vortex separators, advices on design and dimensioning.* Central specialist service Water - Soil - Waste - Residual Waste at the National Institute for Environmental Protection Baden-Wuerttemberg, manual water 4..

Brombach, H; Fuchs, S. [2002]: *Data pool of measured pollution concentrations of dry weather and stormwater runoff in combined and separate sewer.* Final Report, ATV-DVWK Research Fund 2001, Project 1-01.

BSU [2010]: *Guideline - Treatment of stormwater of public areas at the separate sewer system.* Free Hanseatic City of Hamburg.

BSU [2006]: *ecentralized and nature-orientated stormwater management, A guide for planners, architects, engineers and contractors.* Ministry of Urban Development and Environment, Free Hanseatic City of Hamburg.

Buge, F.-M. [2011]: *Re: Road drainage* of 20 April 2011. Senate Department for Health, Environment and Consumer Protection, Division II - Integrative Environmental Protection - Water Authority, e-mail: Frank-Michael.Buge@senguv.berlin.de.

Buschmann, B. [2011]: *Your supplement reques from 04/19/2011* of 04/28/2011. Ministry of Regional Development and Traffic of Saxony-Anhalt, e-mail: Britta.Buschmann@mlv.sachsen-anhalt.de.

BWK-M 3 [2007]: *Drainage of immission oriented demands on combined wastewater and stormwater discharges with consideration of local conditions.*

leaflet 3, 4. version, Association of Engineers for Water Management, Waste Management and Land Improvment.

Chebbo, G. [1992]: *Solids of urban discharges during wet weather: Characterization and treatability.* (Dissertation). National School of Bridges and Highways, Paris, France.

DESTATIS [2007]: *Sustainable Developement in Germany.* Indicator report 2006, Federal Statistical Office, Wiesbaden.

DESTATIS [URL]: *www.destatis.de.* Federal Statistical Office Germany, Accessed at 04/28/2011.

Dierkes, C.; Geiger W.F. [1999]: *Decontaminating effect of the biological active soil zone at traffic-related impairment of soil quality.* 174 pages, report, commissioned by the Federal Highway Research Institute FE 05.107/1996/GGB, Bergisch-Gladbach.

DIN 4049-3 [1994]: *Hydrology – Part 3: Terms for the quantitative hydrology.* German Institute for Standardization, Beuth Publishing.

DIN EN 752 [2008]: *Drain and sewer systems outside buildings.* German Institute for Standardization, Beuth Publishing.

DIN EN 858 [2002]: *Separator systems for light liquids (e. g. oil and petrol).* German Institute for Standardization, Beuth Publishing.

Dobner, I.; Holthius, J.-U. [2007]: *Development of a modular, decentralized plants filter to protect stormwater percolation measures.* AiF-project No.: 13601 N / 1 and N / 2 Joint final report for the period: 01.12.2003 to 30.11.2006. Project Manager University Bremen: Prof. Dr. Wolfgang Heyser, Prof. Dr. J. Warrelmann, Project University Bremen: Prof. Dr. B. Mahro, Bremen.

DWA [no year]: *Wastewater II - Wastewater Treatment.* German Association for Water Management, Weimar.

DWA-A 138 [2005]: *Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water.* DWA German Association for Water Management, Sewage and Waste.

DWA-M 178 [2005]: *Recommendations for planning, construction and operation of retention soil filters for further stormwater treatment in the combined and separate system.* DWA German Association for Water Management, Sewage and Waste.

EC [2011]: *WHITE PAPER: Roadmap to a Single European Transport Area - Towards a competitive and resourceefficient transport system.* European Commission, Brussels.

Eckhardt, H., et al. [2002]: *Abwassertechnik 1+2* Hochschule Rhein Main, Fachbereich Architektur & Bauingenieurwesen, Wiesbaden.

EU [URL]: *http://presseportal.eu-kommission.de/index.php?id=106&tx_ttnews[tt_news]=|&type=98.* Press Portal Europe Direct: Questians and Answers: Trans-European Networks, as of 04/06/2011, Accessed at 07/28/2011.

EU [URL]: *http://europa.eu/legislation_summaries/other/l24094_de.htm.* Summary of EU legislation, common guidelines for the development of trans-European transport network; as of 07/27/2010, Accessed at 07/20/2011.

EU [URL]: *http://europa.eu/pol/env/index_de.htm.* Activities of the European Union - the environemnt, protecting, obtaining and improving the word around us, Accessed at 06/22/2011.

EU-Directive 2000/60/EC [2000]: *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy* ; EU Office Journal L327, p. 1, last amended by Direction 2008/105/EC, EU Office Journal L348, p. 48.

EU-Directive 2006/11/EC [2006]: *Directive 2006/11/EC of the European Parliament and of the Council of 15 February 2006 on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community* ; EU Office Journal L 64, p. 52.

EU-Directive 2006/118/EC [2006]: *Directive 2006/118/EC of the European Parliament and the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration* ; EU Office Journal L 372, p. 19, L 53, p. 30, L 139, p. 39.

EU-Directive 91/271/EEC [1991]: *Council Directive of 21 May 1991 concerning urban waste water treatment* ; EU Office Journal L135, p.40, last amended by Regulation (EC) No. 1137/2008, EU Office Journal L 311, p.1.

Federal Minister for Transport (ed.) [1991]: *Landscape - determination of the sensitivity, intervention assessment and simulation of possible future states.* Series Research Road and Traffic Engineering, Issue 610, Bonn, Bad Godesberg.

Feldhaus, R.; et al. [no year]: *Measures for storm water treatment in municipal separate systems using the example of the administrative district of Cologne.* Cologne University of Applied Sciences, Cologne.

Feldhaus, R.; et al. *Measures for storm water treatment in municipal separate systems using the example of the administrative district of Cologne.* Cologne University of Applied Sciences, Cologne.

FGSV [2002-b]: *Instructions for percolation of stormwater in the streets.* Research Society for Road and Traffic, Municipal Road Commission, 2002 edition, Cologne.

FGSV [2002-a]: *Guideline for structural measures on roads in water protection areas* (= Richtlinie für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten - RiStWag). Research Society for Road and Traffic, Working Group of earthworks and foundations, FGSV Publishing GmbH, Cologne.

FGSV [2011]: *Guidance about control and maintenance of drainage systems on roads outside urban areas.* Research Association for Roads and Traffic e.V.; Infrastructure Management Group, issue 2011, Cologne.

Fröhlich, K. [2009]: *Expectations regarding the new water law - with particular reference to nature conservation legal requirements for water legal decisions.* Handout for presentation at the symposium "The new BNatschG and WHG", NUT at 09/11/09, unpublished, Wiesbaden.

G+L [2010]: *Floodplains are paying off. A study shows that the restoration of floodplain is ecologically and economically sensible.* Garten + Landschaft Issue 10/2010, DGGL (Ed.) Callwey Verlag, Munich.

Göttle, A. [1978]: *Causes and mechanisms of stormwater pollution - A contribution to the modeling of runoff quality in urban areas.* Institute of Civil

Engineering Technical University of Munich, reports from Water Quality Management and Health Engineering, Issue No. 23, Munich.

Grotehusmann, D. [2009]: *Treatment systems for road runoff.* Conference proceedings of the seminar DWA "road drainage" on 19 November 2009 in Lehrte p. 1 / 21 to 21/21, Lehrte.

Gruening et al. [2010-b]: *Stormwater treatment in compact systems.* At: VBI consulting engineers - Magazine for Planning and Buildings, Issue 7/8 2010, p. 30-33.

Gruening et al. [2010-a]: *Final report on the research project: Comparison of the possibilities of centralized and decentralized stormwater treatment measures for two catchments.* Dr. Pecher AG, engineering Office Reinhard Beck, WSW Energy and Water Ltd, Wuppertal.

Gürcke, F. [2011]: *Road drainage.* Ministry of Agriculture, Environment and Consumer Protection of Mecklenburg-West Pomerania, e-mail: F.Guercke@lu.mv-regierung.de.

Heinzmann, B. [1993]: *Characteristics and further treatment of urban storm runoff.* Environmental technology, progress reports, VDI, Series 15, No. 113, VDI-Publishing, Berlin.

Heitker Ltd. [2007]: *Guide for modern stormwater management - Innovative drainage systems.* Company Heitker Ltd..

Helmreich, B. [2011]: *Decentralised treatment of road runoff - experiences from England* (ppt) Technical University of Munich, Institute of Water and Environment, Department of Sanitary Engineering. Technical presentation of the seminar "Decentralised treatment of rainfall runoff" in Frankfurt am Main, 12 May 2011, Frankfurt.

HWag [2005]: *Hamburg Water Act* of 01.09.2005, Hamburg Law Gazette p. 377, last amended on 14.12.2007, Hamburg Law Gazette p. 501.

HWG [2010]: *Hessian Water Act* (= Hessisches Wassergesetz - HWG) of 14 December 2010 (Law Gazette p. 548).

IMBW a. UMBW [2002]: *Additional requirements for the application of RiStWag.* Issue 2002 in Baden-Wuerttemberg.

IMBW a. UMBW [2008-b]: *Technical rules for discharge and treatment of road surface water* of 01/01/2008.

IMBW a. UMBW [2008-a]: *Common Administrative Regulation the Interior Ministry and the Environment Ministry on the removal of road surface water* (= Gemeinsame Verwaltungsvorschrift des Innenministeriums und des Umweltministeriums über die Beseitigung von Straßenoberflächenwasser - VwV-Straßenoberflächenwasser) of 25 January 2008 - Az.: 63-3942.40/129 and 5-8951.13.

Imhoff, K. [1993]: *Handbook of Urban Drainage.* 28th Edition, Oldenbourg Publishing, Munich, Wien.

IndVO [2010]: *Regulation on the discharge or inserting of wastewater containing hazardous substances in public water systems* (=Verordnung über das Einleiten oder Einbringen von Abwasser mit gefährlichen Stoffen in öffentliche Abwasseranlagen - Indirekteinleiterverordnung VGS) of 13 December 2006, last amended by the Regulation of 29 July 2010 (Law Gesetz p. 278).

Information and Technology NRW (ed.) [2010]: *Statistical Yearbook of Northrhine-Westphalia 2010.* 52nd Volume, Düsseldorf.

ITP a. BVU [2007]: *Forecast of Germany-wide transport interconnections 2025.* Intraplan Consult (Munich) on behalf of the Federal Ministry of Transport, Building and Urban Affairs FE-Nr. 96.0857/2005, Munich/Freiburg.

KA No. 4 [2011]: *Knowledge and experience in the application of the worksheet DWA-A 138 - Part 1: Qualitative Information.* In: KA - Korrespondenz Abwasser, Abfall; Volume 58, No. 4, p. 332-338.

KA No. 5 [2011]: *Knowledge and experience in the application of the worksheet DWA-A 138 - Part 1: Quantitative Information.* In: KA - Korrespondenz Abwasser, Abfall; Volume 58, No. 5, p. 442-450.

Kalbskopf [1966]: *Publications of the Institute for Urban Water Management of the Leibniz Universität Hannover.* Issue 24, Hannover.

Kasting, U. [2003]: *Cleaning efficiency of centralized systems for the treatment of discharges of heavily traveled roads.* (Dissertation). Publication Series of the Department of Urban Water Management of the University of Kaiserslautern, Volume 17, Kaiserslautern.

Kasting, U.; Grotehusmann [2009]: *Comparison of the cleaning power of retention soil filters and percolation systems on federal highways.* 95 pages, research road and traffic engineering, Issue 1024, BMVBS, Road Dept., Bonn.

Kocher, B. [2011]: *Retention capacity of soils.* Federal Highway Research Institute. Handout for the seminar: "Decentralised treatment of rainfall runoff - Status quo and future developments" at the FH Frankfurt am 12.05.2011, unpublished, Frankfurt.

Kocher, B. [2008]: *Contaminant levels of banquet material - nationwide data analysis.* Reports of the Federal Highway Research Institute, traffic engineering series, Book V 167, 72 pages, NWVerlag, Bremerhaven.

Kocher, B. [2006 & 2007]: *Substance input in road soils - measuring period 2005/2006 and 2006/2007.* Reports by the Federal Highway Research Institute, Books V 198 and V 199, NW Verlag, Bremerhaven.

Kocher, B.; Wessolek, G. [2003]: *Relocation of road-related substances with leachate.* 99 pages, Research Road and Traffic engineering, Issue 864, Federal Ministry for Transport, Building and Housing, Road Dept., Bonn.

Krauth, K.; Stotz, G. [2001]: *Effect of stormwater sedimentation tanks for the cleaning of stormwater.* KA Korresponden Abwasser, Abfall (48), No. 5, p. 639 - 650.

Krusic, M. [2011]: *MASH-projekt proposal in March 2011.* University of Maribor, Ljubljana, unpublished.

Lambrecht, B.; Fuchs, S. [2008]: *Soil investigations in the context of the development project "percolation of rainwater from paved roads".* Fa. BioPlan behalf of the Bavarian State Office for the Environment (supplement to the final report Nadler, Meissner 2007).

Lammersen, R. [1997]: *The effects of urban drainage on the nutrient balance of running waters.* Sieker, Series of Urban Drainage and Water Protection, Volume 15, SUG-Publishing, Hannover.

Lange, G.; et al. [2001]: *Effectiveness of drainage basins in the area of federal highways.* Research road construction and road traffic 861, Federal Ministry of Transport, Bonn.

LAWA [1998]: *Guidelines for the implementation of dynamic cost comparison calculations.* Working Group on Cost-benefit studies in water management, Regional Working Group on Water.

Leisse, R. [2008]: *Systems for decentralized treatment of stormwater in the separation system* (Diploma thesis). Cologne University of Applied Sciences.

LfU [1997]: *Vortex separators: Advices on the design and dimensioning.* State Agency for Environmental Protection Baden-Wuerttemberg, manual water 4, Volume 5, Karlsruhe.

LfW Bavaria [1999]: *Percolation of stormwater of paved surfaces.* Interim report, development projekt Bavarian State Office of Water Management.

LUBW [2005]: *Work tools for handling with stormwater in urban areas.* State Agency for Environmental Protection Baden-Wuerttemberg, Karlsruhe.

LWG - Rhineland-Palatinate [2004]: *Water Act for the state of Rhineland-Palatinate* (=Wassergesetz für das Land Rheinland-Pfalz - LWG) in the version of 22 January 2004 (Law Gazette p. 53), last amended by the Article 52 of the Act of 9 March 2911, Law Gazette p. 47.

LWG NRW [1995]: *Water Act for the State of Northrhine-Westphalia* Ministry, Law Gazette NRW p. 296 / Assembly of applicable laws and regulations NRW p. 77.

LWG SH [2008]: *Water Act for the State Schleswig-Holstein* of 02/11/2008, last amended on 12/15/2010, Law Gazette Schleswig-Holstein p. 850.

Marschner, S. [2008]: *Monitoring of genetically modified organisms: implementation of appropriate standardized procedures for GMO monitoring* (master thesis) University Nürtlingen, Reutlingen, Stuttgart, Nürtlingen.

MBV-NRW a. MUNLV-NRW [2010]: *Drainage Engineering measures on federal highways and country roads.* according to the circular of the Ministry of Environment and Conservation, Agriculture and Consumer Protection, III.1 - 30-05/123/124.

Merten, Oliver Dr. [2011]: *Road drainage; your request of 6 April.* Ministry of Environment, Health and Consumer Protection of Brandenburg, e-mail:Oliver.Merten@MUGV.Brandenburg.de.

Meyerholt, U. [2010]: *Environmental legislation.* 3rd revised editition, BIS publishing house of the Carl von Ossietzky University of Oldenburg, Oldenburg.

MLUR Brandenburg [2001]: *Guidelines for environmentally responsible and cost-effective stormwater management in Brandenburg.* Ministry of Agriculture, Environmental Protection and Regional Planning of Brandenburg, Potsdam.

MLUR SH [2002]: *Instruction on the evaluation of hydraulic boundaries in rivers at discharges of stormwater from separate sewer systems.*.

MLUR SH [1992]: *Technical regulations for construction and operation of facilities for stormwater treatment in separate sewer system* Announcement of the Ministry of Nature, Environment and Regional Development, XI 440/5249.529, last amended on 15.04.2002.

Morin, A., et al. [2008]: *Advanced mechanical stormwater treatment - Numerical simulations of a counter flow particle separator.* 11th International Conference on Urban Drainage, Edingburgh, Scotland, UK.

MUNLV NRW [1998]: *Stormwater disposal pursuant to § 51a of the state water law NRW.* (= Niederschlagsentwässerung gemäß § 51a des Landeswassergesetztes NRW). Circular of the Ministry of Environment, Spatial Planing and Agriculture, IV B5 - 673/2-29010 / IV B6 - 031 002 0901.

MUNLV NRW [2004]: *Demands on Precipitation Drainage in the separation system.* (= Anforderungen an die Niederschlagsentwässerung im Trennverfahren) Circular decree of Ministry of Environment and Conservation, Agriculture and Consumer Protection of North Rhine-Westphalia - IV-9 031 001 2104 - from 26.05.

Nadler, A.; Meißner, E. [2001]: *Results of a pilot plant for the percolation of stormwater from roads.* Korrespondenz Abwasser, Abfall, issue 48, No. 5, pp. 624 - 639.

National Road Construction NRW [2011]: *Planning Guide Road Drainage and Water Protection.* Third Version, Gelsenkirchen.

NWFreiV [2008]: *Stormwater exemption regulation* (= Niederschlagswasserfreistellungsverordnung - NWFreiV) of 1 October 2008. Bavarian State Office for Environment.

Oertel, Annett [2011]: *Re: road drainage.* Saxon State Ministry of Economy, Labour and Traffic, e-mail: Annett.Oertel@smwa.sachsen.de.

RAS-Ew [2005]: *Directive for the construction of roads – Part: Drainage* (=Die Richtlinien für die Anlage von Straßen – Teil: Entwässerung - RAS-Ew). Research institute for road and traffic routes.

REHAU [2010]: *Stormwater Management - Sustainable and effective solutions.* Catalog Stormwater Management, Homepage.

RiStWag [2002]: *Guidelines for structural measures on roads in water protection areas* (= Richtlinien für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten - RiStWag). Research institute for road and traffic routes.

Roth-Kleyer, S. et al. [2010]: *State of the retention soil filters, technology in Germany, field survey from the perspective of the vegetation technique.* In: KA - Korrespondenz Abwasser, Abfall 2010 (57) No. 12, p. 1209 - 1212.

ROVAL [URL]: *http://www.centrifoel.de/.* ROVAL evironmental technologies, Accessed at 07/02/2011.

Rudin, M.; Kaufmann, P. [2006]: *Treatment of high polluted road stormwater.* at: Road and Traffic, No. 7-8, Issue July/August 2006, p. 45-50.

Schäfer, M. [1999]: *Regionalized material flow balances in urban catchment areas - possibilities, problems and conclusions.* (Dissertation). University of Karlsruhe, Karlsruhe.

Schaffner, J., et al. [2010]: *Inflow based investigations on the efficiency of a lamella separator for the treatment of stormwater runoffs.* NOVATECH 2010.

Schmitt, T.G.; Welker, A. [2006]: *Emissions of hazardous substances from the sewage system in the context of the WFD.* Final report, TU Kaiserslautern, Department of Urban Water Management.

Schriefer, T. [2005]: *Stormwater treatment in prefabricated percolation troughs with substrate.* Reports of Water Quality and Waste Management No. 185, p. 71-96.

Sewage Plant Au/Sieg [URL]: *http://www.klaeranlage-au.de/resources/Sandfang.jpg.* Accessed at 05/10/2011.

Sieker [URL]: *http://www.sieker.de/MKat/rechen_siebe_mischsystem.htm.* Sieker - Measures for Stormwater Management: Combined system - screens / filters, Accessed at 05/09/2011.

Sieker, H. [2010]: *Regenwasserbewirtschaftung - Anforderungen, Verfahren, Messung* (ppt). Ring lectures TU Dresden, Dresden.

Sommer, H. [2007]: *Treatment of road discharges: Systems for Treatment and Filtration of road discharges in areas with separate systems - new developments and investigations -* (Dissertation). University of Hannover, Hannover.

Sommer, H., et al. [2002]: *Measuring studies the function of a trough-trench system.* GWF water / sewage, No. 12.

Stachel; et al. [2007]: *Contaminants in Hamburg highway waters and their assessment taking into account the EC Water Framework Directive (WFD).* Roads and highways 6.2007, p. 326 - 333, Cherrytree Publisher.

STALA-BW [URL]: *http://www.statistik.baden-wuerttemberg.de/Pressemitt/2011239.asp.* Land use in 2010 with 6.6 hectares per day in the compare to last year continued to decline; Press release dated 06/14/2011 No. 239/2011. Statistical Office of Baden-Wuerttemberg, Accessed at 08/04/2011.

STALA-BW [URL]: *http://www.statistik.baden-wuerttemberg.de/Veroeffentl/221809001.asp.* Information on the publication of the brochure "Land Use in the municipalities of the counties." Statistical Office of Baden-Württemberg, Stuttgart, Accessed at 08/05/2011.

Statistical Office of Hamburg and Schleswig-Holstein (ed.) [2011]: *Statistical Yearbook Schleswig-Holstein 2010/2011.* Hamburg.

Statistical Office of Hamburg and Schleswig-Holstein (ed.) [2011]: *Statistical Yearbook Hamburg 2010/2011.* Hamburg.

Statistical Office of Saxony-Anhalt [URL]: *http://www.statistik.sachsen-anhalt.de/Internet/Home/Daten_und_Fakten/3/33/331/331111/Flaechen__tatsaechliche_Nutzung_nach_Kreisen_2009.html.* Floor area in 2009 by type of actual use, Accessed at 07/17/2011.

Statistics Office Berlin-Brandenburg [2010]: *Statistical Yearbook 2010 Brandenburg.* Statistics Office Berlin-Brandenburg, Potsdam.

Statistics Office Berlin-Brandenburg [2010]: *Statistical Yearbook 2010 Berlin.* Statistics Office Berlin-Brandenburg, Potsdam.

SUBVE [2010]: *RainWater - naturally, dezentralized, manage.* Free Hanseatic City of Bremen.

SWG [2004]: *Saarland Water Act* (= Saarländisches Wassergesetz - SWG) in the version published on 30 July 2004 (Official Gazette p. 1994), last amended by the Act of 18 November 2010 (Official Gazette p. 2588).

TEEB [2010]: *TEEP-report: The Economics of Ecosystems and Biodiversity.* Chapter 5.

Thuringia [2002]: *Cost ratios for low-cost municipal wastewater treatment in the Free State of Thuringia.* Ministry of Agriculture, Nature and Environment of the Free State of Thuringia, Catalog 2002.

TLUG [1996]: *Directive on the removal of stormwater in Thuringia* (Richtlinie zur Beseitigung von Niederschlagswasser in Thüringen). Thuringian State Institute for the Environment, Publication Series of the Thuringian State Institute for Environment No 18/96, Jena.

TRENOG [2008]: *Technical regulations for the harmless discharge of collected stormwater into surface waters* (=Technischen Regeln zum schadlosen einleiten von gesammeltem Niederschlagswasser in oberirdische Gewässer - TRENOG) of 17 December 2008 Az.: 52e-U4502-2008/28-1a.

UBA [2001]: *Progress report: Removal of copper and zinc from roofs, gutters and downspouts by precipitation.* Federal Environment Agency.

UBA [2004]: *Measures to reduce emissions into the water for copper, zinc and lead.* Final technical discussion Fraunhofer ISI (Karlsruhe), Federal Environmental Agency, Berlin.

UBA [URL]: *http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/theme.do?nodeIdent=2333.* Federal Environment Agency: Traffic Network as of 2010, Accessed at 07/26/2011.

UFT [URL]: *http://www.uft-brombach.de/uploads/pics/0233-Wirbelabscheider.jpg.* UFT - Environmental and Fluid Engineering Dr. H. Brombach GmbH, Accessed at 05/12/2011.

Uhl, M. [2006]: *Retention soil filters for treatment of stormwater runoff.* In: GP - Gesteins-Perspektiven 4 /2006, Special print: Information of the German Federal Association of gravel and sand industry, BKS News p. 1-4.

Uhl, M. et al. [2006]: *ESOG - Discharge of the outflowing surface water from roads to waters.* Ministry of Environment and Conservation, Agriculture and Consumer Protection of Northrhine-Westphalia, Muenster.

Uhl, M.; et al. [2010]: *Development of test methods for systems for decentralized stormwater treatment in the separation system - Final Report.* German Federal Environmental Foundation, Osnabrück.

Uhl, M.; Grotehusmann, D. [no year]: *Recommendations for action for handling with stormwater - ATV-DVWK Advisory Leaflet M 153.*.

UMBW [2007]: *Regulation of the Ministry of Environment on the decentralized Removal of Stormwater* (=Verordnung des Umweltministeriums über die dezentrale Beseitigung von Niederschlagswasser) of 22 March 1999, Law Gazette p.157, last amended by Article 127 of the Regulation of 25 April 2007, Law Gazette, p. 252.

Waltz, N.; Ceko, R. [2011]: *Quantity, properties and treatment of road runoff in the German states* (Interdisciplinary Project) Hochschule RheinMain, University of Applied Science, Wiesbaden.

Wassmann, H., Klein, G. [1994]: *Expert report on the installation of cleaning equipment for storm water to waters of Berlin.* Institute for Water, Soil and Air Hygiene of the Federal Health Office (since 07/01/1994 Federal Environmental Agency), B3 IV, commissioned by the Senate Department for Urban Development Environmental Protection - Water Authority.

Water-Money-Save [URL]: *http://www.wasser-geld-sparen.de/Lexikon-Glossar/Durchflussleistung.html.* Union House Technic GmbH & Co. KG, Accessed at 07/17/2011.

WG Baden-Wurttemberg [2005]: *Water Act for Baden-Wurttemberg* (=Wassergesetz für Baden-Württemberg - WG) of 20 January 2005 (Law Gazette p. 219), last amended by Article 1 of the Act of 29 July 2010 (Law Gazette No. 13, p. 565) came into force on 1 January 2011.

WHG [2009]: *Act for the Regulation of water balance* (= Gesetz zur Ordnung des Wasserhaushalts - Wasserhaushaltsgesetz - WHG) of 31 July 2009; Federal Law Gazette p. 2585; amended by Artikel 12 of the Law of 11 August 2010, Federal Law Gazette p. 1163.

Wikipedia: Berlin [URL]: *http://de.wikipedia.org/wiki/Berlin.* Berlin, Accessed at 07/17/2011.

Wikipedia: Best practice [URL]: *http://en.wikipedia.org/wiki/Best_practice.* Best practice, Accessed at 07/06/2011.

Wikipedia: TSS [URL]: *http://de.wikipedia.org/wiki/Abfiltrierbare_Stoffe.* Total suspended solids, Accessed at 07/17/2011.

wisy [URL]: *http://wisy.de/ger/Niederschlagskarte.htm.* Wisy - Engineering with nature, Accessed at 04/27/2011.

Xanthopoulps, C. [1996]: *Possibilities and limitations of measures in catchment areas.* At: Hahn, H.H.; Trauth. R. (ed.) Interactions between catchment area and water treatment plant. Series of the Institute for Urban Water Management, University of Karlsruhe (TH), Band 78, Publishing Oldenburg, Munich.

ZASE [URL]: *http://www.zase.ch/images/sandfang.gif.* Special purpose association of the Sewage Region Solothurn-Emme, Accessed at 05/10/2011.

Acknowledgements

At this point I would like to thank for the support during the editing of this thesis, and during my studies.

At the beginning I would like to thank Julian Stolle for the patience, the thoughtfulness and support during the exam weeks and the processing time of this thesis.

Furthermore, I thank my parents for the long-standing support in heights and lows in any form throughout the study period. I also thank for having supported and strengthened me in all my decisions.

My grandparents at both sides, I thank you mostly for the financial support without which such a rapid degree would not have been possible.

A very big thank goes to Prof. Dr.-Ing. H. Eckhardt. By him, my interest in wastewater technology and sanitary environmental engineering has emerged. Thank you for your support and assistance during the entire study period and particularly during this thesis.

Thanks also to my good friend Janina Miketta, who helped me out with her English skills and has supported me in the correction. Thank you.

Another thank to Stefanie Nicolin, which have also supported me in the correction.

Thanks also to Ninja Pfeffermann, who has taken off work many times during the processing time of the thesis.

In the last step I want to thank Nicolas Waltz and René Ceko the for cooperation during this thesis. Without it, a result in the present form would not have been possible. Thank you!