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Interdiciplinary Project

Management of Stormwater on Highways - findings on traffic-related pollutants, selection of appropriate treatment methods and monitoring

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I affirm that I have written this term paper myself and have not used any sources or aids other than those indicated.

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Abstract

The protection of natural water resources, maintenance of the ecological water cycle and thus stormwater management are topics of growing importance in European water policy as well as the Federal Republic of Germany and the federal states. The EU as well as several governments of the Member States (f. e. Germany) have established a wide range of objective and limit values for different pollutant concentrations in different environmental media (f. e. soil, water) or unavoidable emissions. Numerous substances were identified, examined and assessed by their potential impact on the environment or human health in recent studies.

The negative impacts of highway runoff water to the soil or receiving waters have been addressed in several research projects. Since the awareness of water and soil pollution caused by traffic has significantly increased during the last few decades, many regulations, guidelines and recommendations were adopted by various governmental organizations (on different levels) and professional associations.

This term paper provides an overview of the legal and technical frame of stormwater management on highways. Current findings on highway runoff pollution, i. e. the well-researched (f. e. heavy metals) as well as less researched (f. e. PAH) water-hazardous substances (amongst common pollutants like suspended solids) and their elimination, the removal processes and appropriate treatment facilities as well as their selection, maintenance and monitoring were investigated.

It is shown, that the implementation of sustainable and effective management of stormwater on highways exhibits a need for improvement. This could be achieved by monitoring and assessment of highway runoff treatment facilities in practice rather than by the adoption of another regulative approach, since the implementation of the currently effective (waste)water laws are partially deficient and there is still a lack of data relating to the behavior of pollutants in actually operating highway runoff treatment facilities. Although it is bound to certain high expenses, the conduction of monitoring projects for the examination of water quality up- and downstream of treatment facilities allows the gathering of valuable practice information that allows the further improvement of highway runoff treatment, f. e. about interactions between different removal processes, resp. the behavior of pollutants under natural environmental conditions.

Glossary (English-German terminology)

English term	German term
advent of pollutants	Schadstoffaufkommen
agency in charge of highway maintenance	Autobahnmeisterei (AM)
chemical precipitation	Fällung (chem.)
constructed wetlands	Pflanzenkläranlagen
efficiency factor	Wirkungsgrad
Embankment < syn. shoulder, batter>	Bankett (tech., am Straßenrand)
extensive percolation	Flächenversickerung
filterable solid substances < cf. total suspended solids (TSS) >	abfiltrierbare Feststoffe (AFS) < vgl. gesamte ungelöste Stoffe (GUS) >
Flocculation < syn. Coagulation >	Flockung
grit chamber	Sandfang
Highway	Autobahn
highway runoff / road runoff	Autobahnabwasser / Straßenabwasser
highway runoff treatment facility	Autobahnabwasserbehandlungsanlage bzw. Straßenabwasserbehandlungs-anlage (SABA)

Hydrograph	Ganglinie
Hyetometer	Regenmesser
lamella separator	Lamellenabscheider
light liquid separator	Leichtflüssigkeitsabscheider <syn. Leichstoffabscheider>
limit value	Grenzwert
Municipal	kommunal, gemeindlich
pollutant ingress	Schadstoffeintrag
Precipitation	Niederschlag
Precipitation	Niederschlag
precipitation runoff	Niederschlagsabfluss
priority hazardous substances	primäre gefährliche Stoffe (bez. Auf die EU-Wasserrahmenrichtlinie)
Probe	Sonde
rain yield factor	Regenspende
regulatory approval	behördliche Genehmigung
retention soil filter	Retentionsbodenfilter
retro-fitting	Nachrüstung (nachträglicher Einbau von technischen Elementen zur Verbesserung der Leistungsfähigkeit)
shaft percolation	Schachtversickerung

Stormwater < syn. rain water >	Regenwasser
tank percolation	Beckenversickerung
total suspended solids (TSS)	gesamte ungelöste Stoffe (GUS)
trench and pipe-trench percolation	Rigolen- und Rohr-Rigolen-Versickerung
trough percolation	Muldenversickerung
trough-trench percolation	Mulden-Rigolen-Versickerung
trough-trench system	Mulden-Rigolen-System
volatile suspended solids	Schwebstoffe
vortex separator	Wirbelabscheider

List of abbreviations and symbols

abbreviation / symbol	full term
µg/L	microgram per liter
A	surface / area
AOX	adsorbable organic halogen compounds
A_S	percolation area
As	Arsenic
A_U	non-permeable area (paved area, origin of runoff)
BOD_5	biological oxygen demand measured after 5 days
b_{Sp}	mean width of water level
BWK	Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau (association of engineers for water management, waste management and land improvement)
Ca	Calcium
Cd	Cadmium
CO	carbon monoxide
CO_2	carbon dioxide
COD	chemical oxygen demand
Cr	Chromium
Cu	Copper

DIN	Deutsches Institut für Normung (German institute for standardization)
DOC	dissolved organic carbon
DTV	daily traffic volume
Fe	iron
FGSV	Forschungsgesellschaft Straßen- und Verkehrswesen (Research Society for Road and Transportation)
H KWES	Hinweise zur Kontrolle und Wartung von Entwässerungseinrichtungen an Außerortsstraßen (suggestions for the controlling and maintenance of drainage facilities of non-local roads)
Hg	mercury
m	meter
m^2	square meter
Mg	magnesium
mg/L	milligram per liter
mm	millimeter
Mn	manganese
MOTH	mineral oil-type hydrocarbons
N	nitrogen
NH_3-N	nitrate nitrogen

NH_4-N	ammonia nitrogen
Ni	Nickel
NO_X	nitrogen oxides
N_{tot}	total nitrogen
P	Phosphorus
PAH	polycyclic aromatic hydrocarbons
Pb	Lead
P_{tot}	total phosphorus
RAS-Ew	Richtlinien für die Anlage von Straßen, Teil: Entwässerung (Guidelines for the planning and construction of roads, section: drainage systems)
r_{crit}	critical rain yield factor
RiStWag	Richtlinie für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten (Guidelines for structural measures on roads in water protection areas)
Si	Silicon
TOC	total organic carbon
TSS	total suspended solids
V	(flow) velocity
VOC	volatile organic compounds
VSS	volatile suspended solids

WHG	Wasserhaushaltsgesetz
Zn	Zinc
ψ	runoff-coefficient

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1. Introduction

During the last few decades the awareness for the need of environmental protection as well as the sustainable and responsible use of natural resources has increased. In 1977 the first edition of the Federal Nature Conservation Act[1] came into effect, but it soon turned out that there had to be a lot more regulations and specifications set on the legally protected goods, such as air, soil and water. Thus, in addition to the Federal Nature Conservation Act, several laws and guidelines on soil-, immission- and water protection were enacted in the federal republic of Germany, naming for example legally binding limit values for pollutants, emission control or regulations on the handling of noxious substances. The understanding and knowledge of the connection between air/soil/water pollution, its various sources and the possible impact on the environment has become ever clearer. However, the most complex aspect of regulations on emission control is pollution resulting from diffuse sources, such as agriculture or traffic.

[1] Bundesnaturschutzgesetz, BNatSchG

1.1 Problem description

Germany possesses the world's most dense road network [MEINEL, URL; 01/25/2012]. The total traffic area amounts to 17,930.761 km^2 [2]. Within the sixteen federal states of Germany the total traffic area is divided as follows:

Federal state	Total area in km^2	Total traffic area in km^2	Amount in %
Baden-Wurttemberg	35,751.45	1,956.830	5.47
Bavaria	70,549.97	3,382.103	4.79
Berlin	891.45	136.510	13.91
Brandenburg	29,481.95	1,069.560	3.63
Bremen	404.28	48.577	12.02
Hamburg	755.16	93.517	12.38
Hesse	21,114.91	1,421.380	6.73
Lower Saxony	47,634.98	2,429.445	5.10
Mecklenburg-West Pomerania	23,188.98	687.232	2.96
Northrhine-Westphalia	34,088.01	2,402.904	7.05
Rhineland-Palatinate	19,853.58	1,233.429	6.21
Saarland	2,568.66	160.038	6.23
Saxony	18,419.70	766.270	4.16

[2] the total area of Germany is approximately 357,124 km^2

Saxony-Anhalt	20,448.86	783.264	3.83
Schleswig-Holstein	15,799.07	688.595	4.36
Thuringia	16,172.51	671.107	4.15
Total	**357,123.50**	**17,930.761**	**5.02**

Tab.1: Total traffic area in the German federal states [STATISTIK-PORTAL, URL; 01/25/2012 and GENESIS, URL; 01/25/2012]

It must be considered that of the approx. 5 % total traffic area in Germany the actual roadway is projected at 1.2 %, which means that about 3.8 % of the denoted traffic areas are marginal strips, batters, embankments and ancillary facilities like parking areas [SCHÄFER, 2010]. Nevertheless, from table 1 can be seen, that especially the federal city states (Berlin, Bremen and Hamburg) and populous states like Rhineland-Palatine, Northrhine-Westphalia or Hesse have high traffic area rates and need to respond to the pollution resulting from road runoff urgently. Unfortunately, no statistics on the explicit amount of non-local traffic area, especially highways, could be found. However, the length of the non-local road network is ascertained to be 230,782 km, thereof 21,819 km are highways[3] [STATISTIK-PORTAL, URL; 01/25/2012].

Since the run-off coefficient of road surfaces like asphalt pavement is 0.9, which means that approximately 90 % of the precipitation is flowing off, stormwater accumulates on the road surface and absorbs the substances that settled there. It has to be drained off the road surface to maintain the safety to traffic. In the past, runoff water was mostly discharged untreated into the pre-flooders or rivers, which lead to high loads of pollutants in the water bodies, including the ground water. In the present, the importance of highway runoff treatment has been recognized.

[3] evaluation date: 01/01/2011

1.2 MASH-project

Since humanity is facing vast changes in global climate, population growth and availability of natural resources, the European Union is concerned with a wide range of environmental topics. Over the last few decades the EU has developed “some of the world’s highest environmental standards” [EU, URL; 01/28/2012]. Current topics are conservation of biodiversity and protection of endangered species, the efficient use of natural resources, waste-management and the protection of common goods such as air or water. The policy area concerned with Water aims not only to provide clean, high quality water in sufficient quantity to all European citizens, but also to protect all European water bodies from pollution and to make them meet the quality standards.

A research task force of the European Commission, consisting of many different stakeholders in water management, addressed the topic “fresh water” and adopted ten “action lines”:

1. Water resources assessment and surveillance
2. Water resource management at the local/regional level
3. Pollution sources, pathways and impacts
4. Water and wastewater treatment
5. Urban water systems
6. Water in agriculture
7. Water conservation in industry
8. The socio-economic framework
9. International co-operation
10. Promotion of water research

Each action line answers to the four problems pollution, water dissipation, regional and supra-regional water scarcity and the management of crisis situations, which are basically the four fields of work for international water research.

Regarding the goal of combating pollution the EU action line 1, concerned with evaluation and observation of water resources, names not only the immission-based observation of the fresh water resources in general, but also the monitoring and benchmarking of human intervention, which is an emission-based approach that will be discussed later on in this term paper. Also, action line 8, concerned with the socio-economic aspects of water protection and supply, names the goal of evaluating and monitoring of the environmental impact of policies, programs and projects. Action line 5, concerned with urban water systems, names the advent of pollutants caused by stormwater overflows, which can be seen as a recommendation of separate sewage systems for domestic wastewater and stormwater that have been applied in many urban water systems in Germany. The action lines do not explicitly name the treatment of highway runoff, but in accelerating monitoring and emission control in any human intervention such as discharging (treated) wastewater into the receiving waters they still apply for the concerns of the MASH-Project ("Management of Stormwater on Highways).

Generally, the EU collaborative research on water is highly developed, but to meet the "different water management needs" of the Member States and to "better exploit research results for the setting and monitoring of EU policies and related initiatives" the efforts need to be managed in a more efficient way. Under the patronage of the EU a series of projects under the umbrella project SHARP (Sustainable Hydro Assessment and Groundwater Recharge Projects) have been addressing the topic of groundwater assessment and supply [SHARP, URL; 01/292012]. Member States taking part in SHARP are Austria, Germany, Great Britain, Greece, Italy, Malta and Poland. The overriding objective of SHARP is to protect groundwater from pollution and to ensure reasonable groundwater management for the benefit of future generations. The project focuses on transferring knowledge, exchanging experiences and improving techniques, methods and practices especially regarding the local and regional differences throughout Europe. [FRESHWATER, URL; 01/28/2012]

Highways and supra-regional roads are for public use; hence, the treatment of thereby incurred highway runoff is a common task. The Member States must approach this task by translating the European standards and goals into national law such as waste and wastewater legislation. The current status of the implementation of those standards and goals is very different in the Member States of the EU. Compared to other Member States Germany as a country with a dense road network is relatively experienced when it comes to highway runoff treatment.

The MASH-Project can be seen as a “specific extension to the results from SHARP” [PFEFFERMANN, 2011] with the overall objective to develop efficient and practicable highway runoff management throughout the European Union. Member states taking part in MASH-Project are Austria, France, Germany, Italy, Netherlands, Poland and Slovenia. Like SHARP, the MASH-Project aims to exchange knowledge and practical experiences about highway runoff contents, quantities, appropriate treatment (best practice) and management systems, regarding the local and regional differences. One sub-goal is to generally promote surface and groundwater management in less developed European countries (in this case Italy, Slovenia and Poland) and to make them benefit from the knowledge of countries with more experience (in this case Austria, France, Germany and Netherlands). To minimize the risks of further water pollution and environmental impairment the MASH-Project is designated to find approaches and give recommendations for political as well as practical action on the local and regional scale. The results of this cooperation should be considered in the process of improving policies. Infrastructural funds like the “European Regional Development Fund” (ERDF) that aims to adjust regional economic, ecologic and social imbalances by participating in the conversion and development of regions [EU, URL; 91/29/2012] draw upon political implementation of such project results.

In the context of European infrastructure projects like TEN-T (Trans-European Network for Transport) [footer: German: TEN-V “transeuropäisches Verkehrsnetz” bzw. “Trans-European Network – Verkehr”] that comprise the improvement, upgrading and expansion of the European road network the importance of the MASH-Project increases. TEN-T envelopes all kinds of infrastructure (f. e. roads, railways, waterways, ports, airports, intermodal terminals, pipelines and navigation aids) and has the overriding objective of “strengthening economic and social cohesion” in different regions and safeguarding the frictionless functioning of internal markets. To achieve this, a “high quality infrastructure”, providing service, comfort and safety to all users, has to be established throughout the territory of the EU. Estimated measurements are f. e. the completion and connection of necessary road lines and stretches as well as the achievement of interoperability of all network components. Furthermore it is important to enhance the efficiency of existing infrastructure and to regard environmental concerns, which means considering the possible impact the existing and the expanded road network have on the environment. [EU,URL; 01/30/2012]

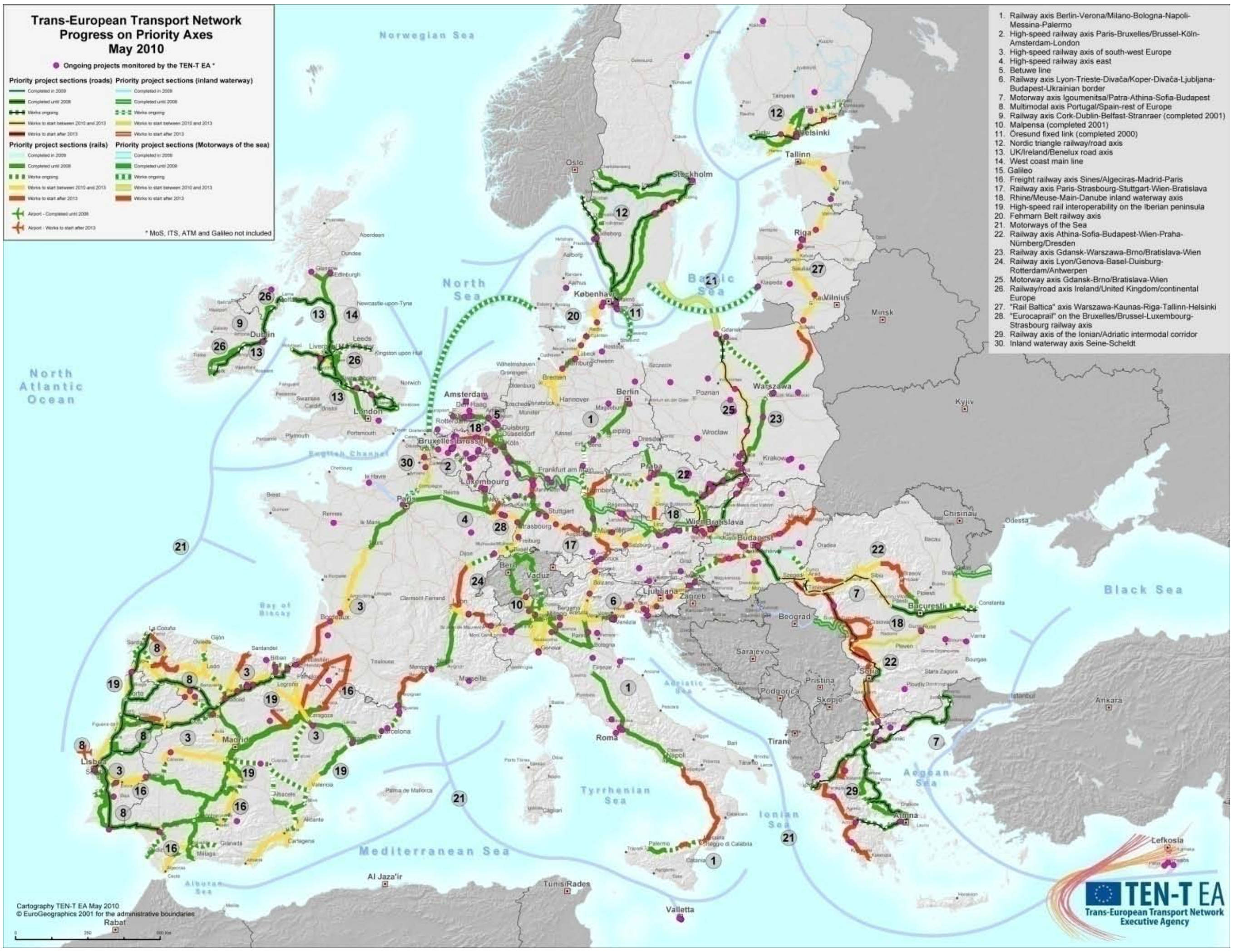

Fig. 1: Trans-European transport network, planning and construction progress on priority axes of different types of infrastructure, effective May 2010 [TENTEA, URL; 01/29/2012]
<u>Solid lines in blue and green</u>: already completed
<u>Dashed lines in green</u>: Works ongoing
<u>Solid lines in yellow and red</u>: Works to start after 2010
<u>Pink dots</u>: currently monitored TEN-T projects (effective May 2010)

1.3 Objectives

In 2011 some preparatory work for the MASH-Project was done by M.-Eng. Anna-Lisa Pfeffermann (master thesis), B.-Eng. René Ceko and B.-Eng. Nicolas Waltz (interdisciplinary project). The legal framework and the state of the art of treating highway runoff were worked out and described. Also, basic information about the compounds of highway runoff water was given. Some sections of this term paper, especially the description of the legal situation, will refer to these projects and term papers. In addition to that, there are some project works parallel to this term paper by Dipl.-Ing. Julia Rempp (interdisciplinary project) and B.-Eng. René Ceko (master thesis).

While the term paper of Ms. Rempp will provide information about the best nature-orientated practice in highway runoff treatment and the thesis of Mr. Ceko will substantiate his work on mechanical, physical and chemical treatment to find out the best practice methods, the present term paper is dedicated to the advent of pollutants in highway runoff water, especially regarding the priority hazardous substances determined by the European water framework directive. Some highway runoff water compounds like heavy metals or filterable solids are well investigated[4]. Other substances like persistent organic pollutants are rarely regarded in highway runoff quality surveys and, when researched, mostly measured by sum parameters like the polycyclic aromatic hydrocarbons (PAH). Individual water-hazardous organic substances, as determined by the European Water Framework Directive[5], are relatively unexplored and will be examined in this project work. Another key aspect of this term paper is the selection procedure of an appropriate treatment method for highway runoff using the example of the German federal state Baden-Wurttemberg. Furthermore the monitoring of highway runoff treatment facilities in the sixteen federal states of Germany will be looked at. An overview on the layout of this term paper will be given in section 1.4 “Structure of this term paper”.

[4] f. e. KOCHER and BEER (2007), DIERKES (no year) and other

[5] priority hazardous substances

1.4 Structure of this term paper

The following chapter (number 2) provides some basic information about the terms and definitions that are used in this term paper as well as an overview of the legal framework that applies for highway runoff treatment in Germany. Chapter 3 first and foremost describes the compounds of highway runoff water with special regard to the priority hazardous substances determined by the European water framework directive (section 3.1). In section 3.2 the various options to treat highway runoff water are shown in an overview of the state of the art, basically drawing upon the detailed depiction by Ms. Pfeffermann, Mr. Ceko and Mr. Waltz. The fourth chapter attends to selection methods of suitable highway runoff treatment facilities in the context of their respective surrounding conditions. Especially the selection method according to the data sheet ATV-DVWK M 153, as practiced in the German federal state Baden-Wurttemberg, is discussed. Chapter 5 deals with the evaluation of highway runoff treatment facilities and describes the development of a testing method for decentralized stormwater treatment in separate sewage systems by the German federal environment foundation[6] (DBU) and the German association for water management, waste and wastewater[7] (DWA). The sixth chapter is dedicated to monitoring of highway runoff treatment in the German federal states regarding the status quo in practice as well as the self-monitoring directives and the state of their implementation. Also, possible all-embracing monitoring programs are prospected. In chapter 7 the results of the work on this term paper are discussed and conclusions are made.

[6] Deutsche Bundesstiftung Umwelt

[7] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.

2. Basic information

2.1 Terms and definitions

In addition to the English – German glossary this section provides definitions of the most important terms that will repeatedly appear in this term paper.

Highway runoff (water)

'Highway runoff water', resp. 'highway runoff' is defined as → *precipitation* water that flows off highway surfaces. In the context of this term paper, the term 'highway runoff *water*' is used when referring directly to ingredients or quality of the water. 'Highway runoff' generally means the precipitation runoff of federal highways, but may also mean the precipitation runoff of non-local roads with a → *traffic density* and pollution loads similar to federal highways, i. e. federal roads.

According to the compendium for the discharge of road runoff into water bodies[8] there is a dependent relationship between the → *traffic density* and the advent of pollutants that threaten groundwater. Runoff from roads with a DTV lower than 2,000 motor vehicles per 24 hours are classified as minor loaded with pollutants. At a DTV of 2,000 to 15,000 motor vehicles per 24 hours the runoff is classified as medium loaded. If the DTV exceeds 15,000 motor vehicles per 24 hours, the road runoff is highly loaded and bears a significant potential to contaminate groundwater and surface waters [Uhl, 2006]. Corresponding to this, the RiStWag (see also section 2.3 "Technical guidelines and standard specifications") name the DTV as a useful criterion to determine the hazard potential of road runoff:

DTV < 2,000 motor vehicles / 24 h	= minor hazard potential
DTV 2,000 – 15,000 motor vehicles / 24 h	= medium hazard potential
DTV > 15,000 motor vehicles / 24 h	= high hazard potential

[8] ESOG-Handbuch

Highway runoff treatment facility

In the context of this term paper ‘highway runoff treatment facilities’ is used as an umbrella term for any facilities (nature-orientated, physical/chemical or in any other way technical) that are built to drain, collect, treat, discharge, percolate or irrigate highway runoff. Some reference term papers employ the term ‘highway runoff treatment plant’, which has basically the same meaning, but relates more to the technical methods than to percolation or irrigation of highway runoff. For reasons of clarity and comprehensibility ‘highway runoff treatment facility’ will be the sole term used.

Groundwater

Groundwater means all water bodies below the soil surface in the saturation zone and in direct contact with the ground resp. subsoil. [2000/60/EC, article 2]

Heavy metals

Heavy metals are an ambiguous group of diverse chemical elements that display metallic properties. There is no clear-cut definition, though. Some definitions use the atomic weight or density, others atomic numbers and position in the periodic table. The group consists of transition metals, metalloids, lanthanides and actinides [WIKIPEDIA, URL 02/03/2012]. A synonymic term occasionally used in literature is ‘toxic metals’, since the exhibit toxic effects on organisms by accumulating and intervening in metabolism. Nevertheless, some heavy metals are important trace elements that are essential for humans, animals and plants. Heavy metals occur in natural environment, but most often are anthropogenic. Sources are f. e. metal processing and smelting, motor vehicles (combustion) or the use of chemicals and materials with heavy metal compounds.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) are a group of organic compounds that consist of several benzene rings. The designation ‘aromatic’ characterizes compounds of a specific molecule structure, of which most have a particular smell. The PAH group is estimated to comprise about 100 sub-types and approximately 10,000 different substances, but not more than half of them are identified yet. Most PAH are toxic to humans, fauna or flora [OETZEL, URL; 02/15/2012]. Common deleterious effects of PAH are cancer, reproductive problems, damage of the organ system or skin irritations. One of the most well-known PAH is benzo(a)pyrene, which is verifiably carcinogenic. Most PAH result from incomplete burning of carbonaceous substances like oil, coal, gas, wood or waste. In low concentrations PAH can be found almost anywhere, even in food[9]. [DHS, URL; 02/03/2012]

Since the itemization of PAH types is complex and expensive, most environmental researches on pollution record PAH as sum parameter or with benzo(a)pyrene as key components.

Precipitation

According to the German Meteorological Service precipitation is the withdrawal of H_2O from the atmosphere that can be observed and/or measured on the earth’s surface in liquid or solid aggregate phase. It can be distinguished in falling precipitation like rain, snow, hail or sleet, awhirl precipitation like drizzle or drifting snow or deposited precipitation like a snow covering, but also dew or rime. Precipitation is measured in millimeters, equal to one liter per square meter. Solid falling precipitations like snow or hail are melted to be measured. [DWD, URL; 01/30/2012]

Synonymic terms are ‘stormwater’ and ‘rainwater’, although, strictly speaking, they only refer to one type of precipitation. However, rain is the most common type of

[9] PAH can get into groceries by detaching from packaging or during the production process

precipitation in Germany, which is why the term ‘stormwater’ will also be used in this term paper.

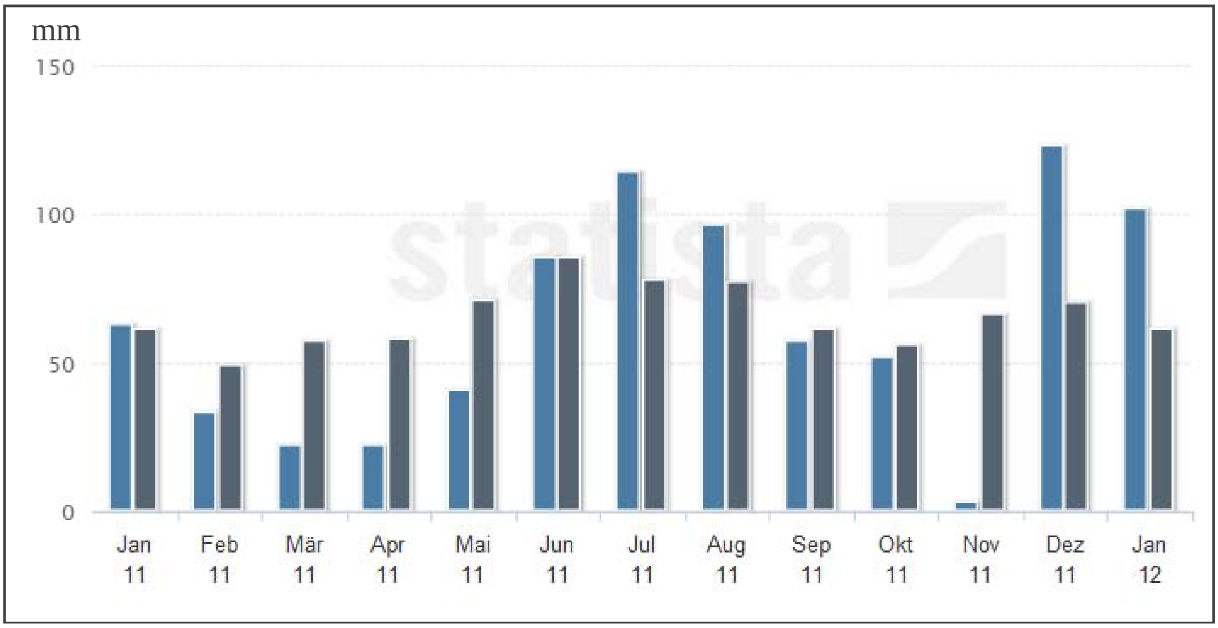

Fig. 2: Average monthly precipitation in Germany from January 2011 to January 2012 (light blue) compared to the longtime monthly average (dark blue) [STATISTA, URL; 02/03/2012]

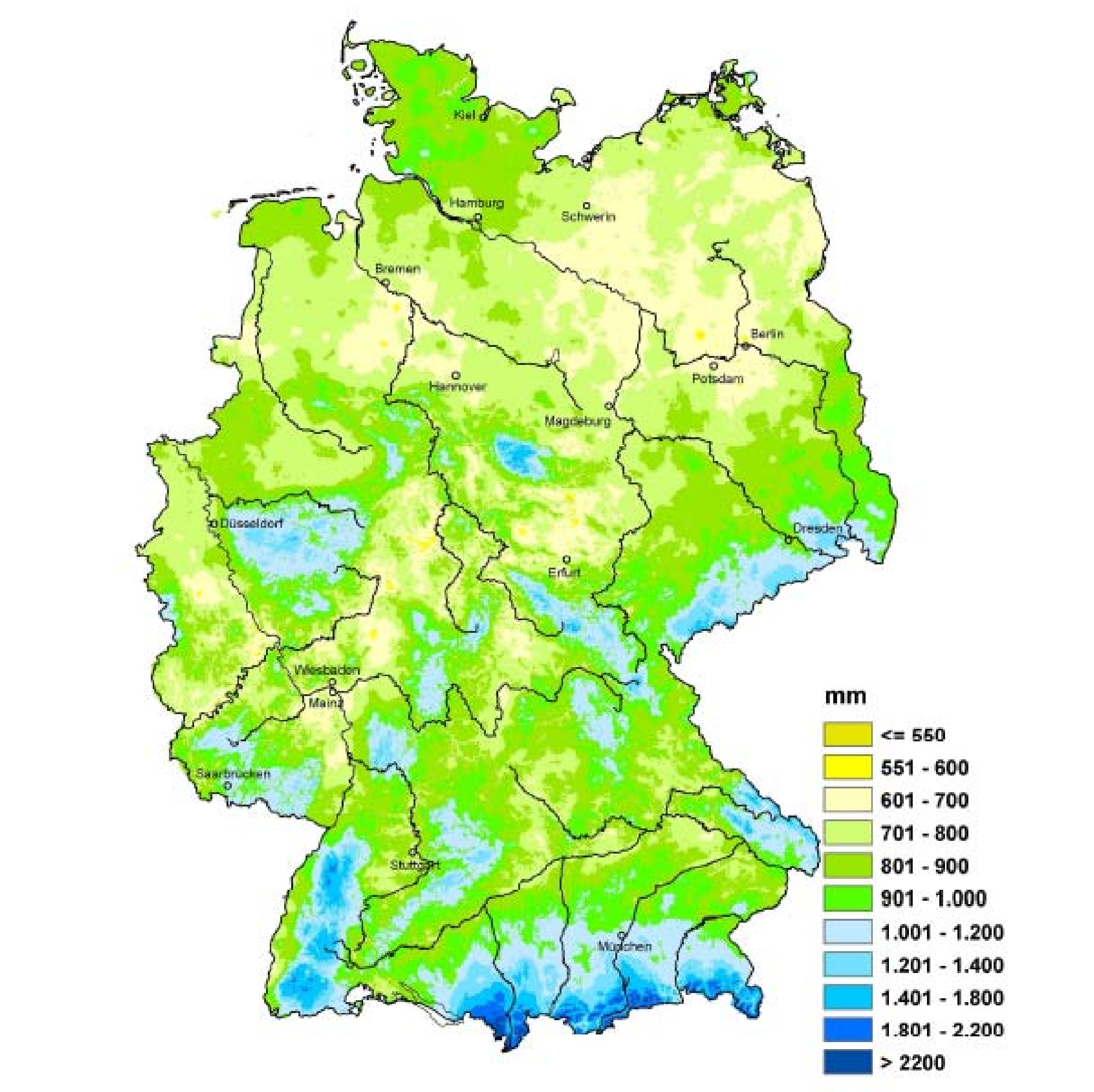

Fig. 3: Average height of precipitation in Germany, year 2010
Data of all Stations and networks of the German Meteorological Service were used.
[DWD, URL; 02/03/2012]

Amount, duration and intensity of precipitation have a certain effect on the washout of pollutants from road surfaces and the quality of → *highway runoff water*. For instance, heavy rainfalls after dry periods can cause a significant deflection of average pollution concentrations. Highest pollution concentrations are mostly found “in the ‘first flush’ of moderate storm events following extended dry periods” [Winkler, 2005].

Apart from the meteorological meaning precipitation can also describe the result of a chemical reaction, which is the formation of solids out of a solution. This phenomenon will be described in the chapter on highway runoff treatment. To obviate misunderstandings it will be always referred to as '*chemical* precipitation'.

Surface waters

According to the European Water framework directive 'surface water' means all "inland waters, except groundwater; transitional waters and coastal waters, except in respect of chemical status for which it shall also include territorial waters." [2000/60/EC, article 2]

In the context of this term paper, 'surface waters' will not be used for marine waters, but for inland water bodies excluding ground water (basically rivers, streams and lakes). It will first and foremost be used to describe waters in which treated or untreated → *wastewater* is discharged. Synonymic terms that are used in this term paper are 'pre-flooders' and 'receiving waters'.

Traffic density

The traffic density, expressed as daily traffic volume (DTV), is given in motor vehicles per 24 hours. Roads with a DTV of 5,000 to 15,000 motor vehicles per 24 hours are for example single-carriageway federal roads, while dual-carriageway federals roads and federals highways usually exceed a DTV of 15,000 motor vehicles per 24 hours [BADEN-WURTTEMBERG, 2008]. The traffic density of German federal highways varies extremely from rural to agglomeration areas and there are certain 'hot spots' (mostly junctions) that are particularly affected by high traffic volumes. The most frequented German highway interchange is the 'Frankfurt Junction'[10] with a DTV of 310,000

[10] Frankfurter Kreuz

motor vehicles per day[11] due to its connection to the agglomeration area Rhein-Main as well as the Frankfurt airport [WIKIPEDIA, URL; 02/03/2012].

Wastewater

The Federal Water Act of Germany[12] defines wastewater as “water altered in its properties by domestic, industrial, agricultural or other use including the water flowing off combined with it in arid weather periods as well as collected precipitation water flowing off from built-up and paved areas.” [WHG, 2011, § 54]

Combined sewage system

Resulting from the conviction that stormwater should be discharged out of areas of settlement as fast as possible the combined sewage system was the conventional method of drainage until the late 1990s. Domestic wastewater and collected precipitation runoff are discharged in the identical conduits and pipes and supplied to a centralized treatment facility. Due to the limited capacities of those wastewater treatment plants the separate sewage system requires additional stormwater treatment facilities and overflows for relief. [ATV TASK FORCE, 1996]

[11] evaluation 2004

[12] Wasserhaushaltsgesetz, WHG

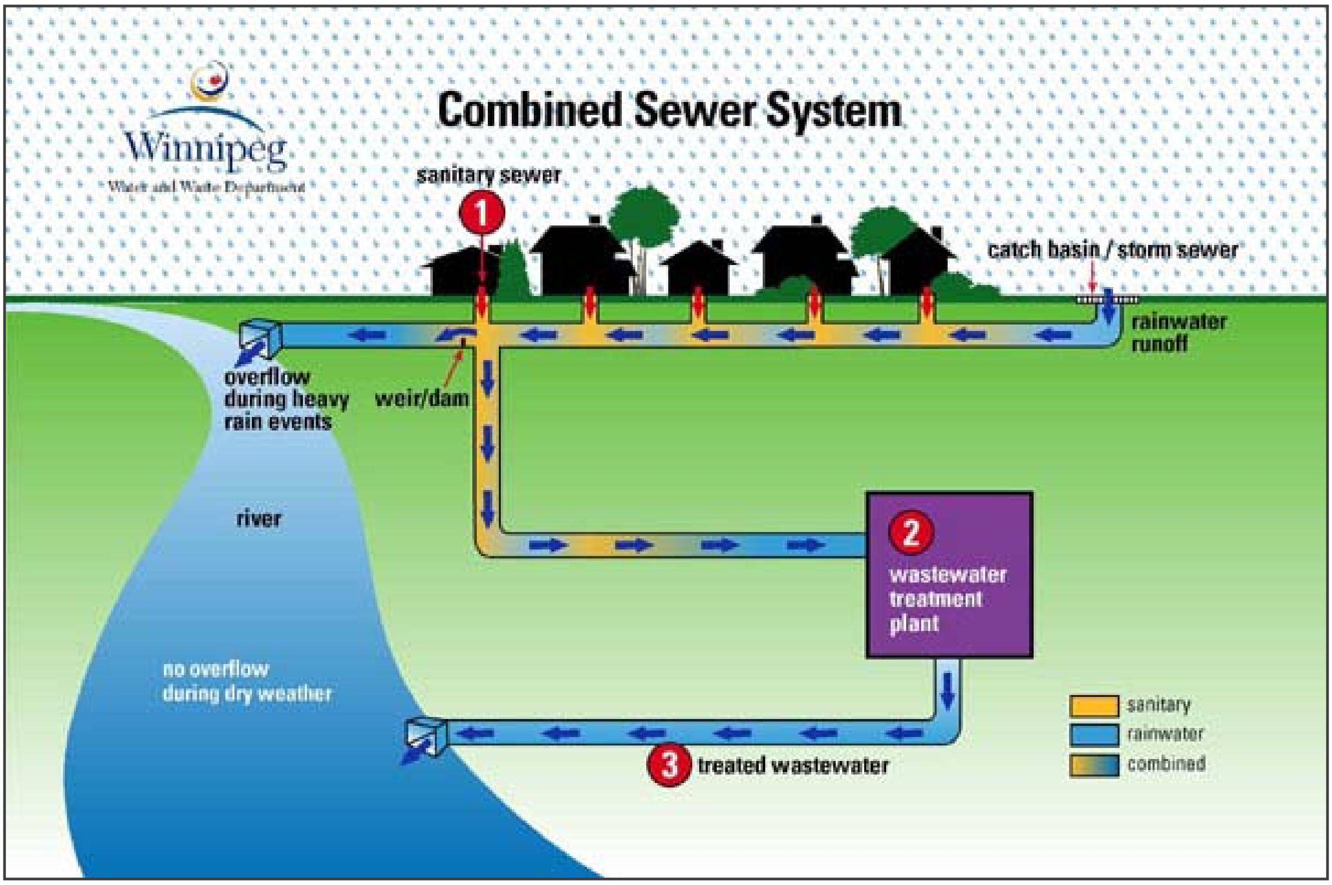

Fig. 4: Combined sewage system scheme [WINNIPEG A, URL; 02/20/2012]

Separate sewage system

In contrast, the separation system requires different conduits and pipes for domestic wastewater and collected precipitation runoff. This system bears many advantages for urban water management, f. e. the reduction of centralized treatment facility workloads, the increase of groundwater recharge rates, the percussion-type[13] stresses of receiving waters from overflows (increased pollutant concentration from mingled wastewater and stormwater) or the mitigation of low water and flood stress ratio. [ATV TASK FORCE, 1996]

[13] hier: stoßartig

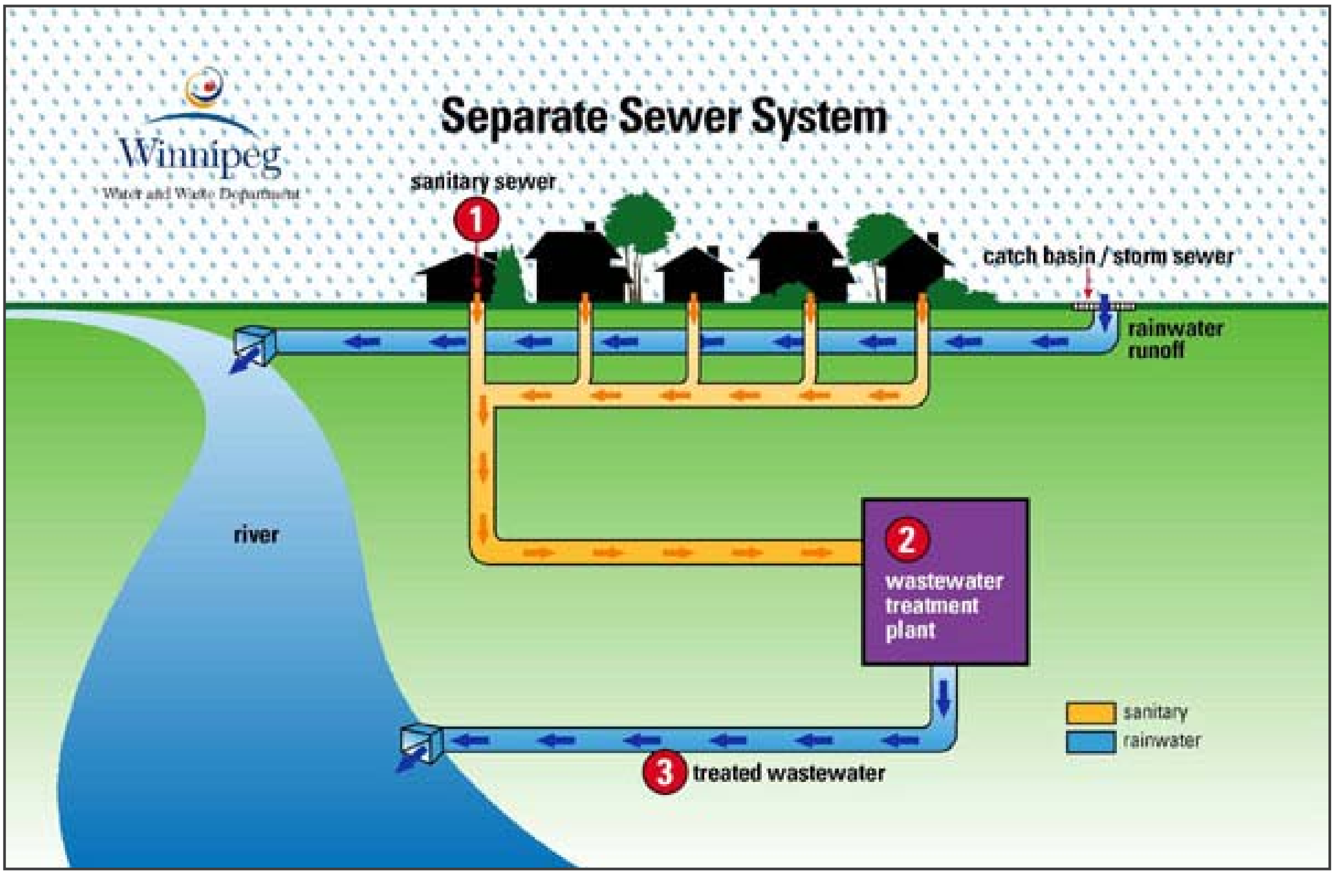

Fig. 5: Separate sewage system scheme [WINNIPEG B, URL; 02/20/2012]

2.2 Legal framework

This section attends to the legal framework within which management of stormwater on highways resp. highway runoff treatment is performed. It considers the three legislative levels of Europe (European level), the Federal Republic of Germany (national level) and the German federal states (state level).

2.2.1 European law

Generally, it can be said that European law overrides the federal law, as far as water policy is concerned. Due to the Maastricht Treaty and the Lisbon Treaty the European Community can implement laws superior to the law of the Member States in defined policy fields, including environmental, climate and energy policy. [PFEFFERMANN, 2011]

The EU has enacted several directives that must be applied in highway runoff treatment. Amongst the directive for protection of groundwater against pollution (Groundwater directive, 2006/118/EC, 2006), the directive on urban wastewater treatment (Urban Wastewater Directive, 91/271/EEC, 1991) and the directive on pollution caused by certain dangerous substances (Dangerous Substances Directive, 2006/11/EC, 2006) the European Water Framework Directive (2000/60/EC, 2000), short WFD, is most important.

The overriding purpose of the WFD is the establishment of a regulation framework to prevent the deterioration of aquatic ecosystems, to promote the sustainable use of water resources and to safeguard the progressive reduction of groundwater pollution. The Member states must ensure the implementation of the statutory provisions of the WFD by compiling action plans and programs of measurements according to article 11. The WFD demands adherence of several water quality objectives. Article 4, section 1 engages the Member States to ensure a “good status” of all waters until 2015. It distinguishes “good chemical status” and “good ecological status” for surface waters[14] and “good chemical status” and “good quantitative status” (i. e. a balance between abstraction and recharge) of groundwater. This does not only mean an impairment restraint[15] for all water bodies, but also a gradual decrease of pollutants. The targets and requirements to achieve these statuses are given in the attachments to the WFD.

According to article 10 of the WFD the Member States have to ensure the establishment of emission control based on the best available techniques (state of the art) or the implementation of the relevant emission values given by several council directives and the directives named in the attachments to the WFD.

Like all EU directives, the WFD is legally binding as regards the objective values and the adherence of requirements. Yet, the ways and means of implementation and the

[14] artificial or heavily modified water bodies are to be developed into water bodies with good ecological potential [2000/60/EC, article 4]

[15] Verschlechterungsverbot, [2000/60/EC, article 4, section 5c]

choice of appropriate measurements are left to the Member States. [PFEFFERMANN, 2001]

In Germany the requirements of the WFD were implemented into the water legislation, mainly the Federal Water Act (as seen in section 2.2.2).

2.2.2 Law of the Federal Republic of Germany

Due to an amendment of the constitution[16] in 2006 the German water legislation features concurrent legislative competence, which means, if the Federal Republic of Germany has issued regulations, the federal states cannot adopt their own legislation. Yet, the German laws pertaining water and waterways comprise opening clauses that allow the federal states to adopt specific regulations.

Concerning the abatement of highway runoff, there are several important laws, not only concerning water legislation, but also soil protection laws. The most important laws are the Federal Water Act[17] (2009), the Wastewater Ordinance[18] (2004), the Federal Soil Protection Act[19] (1998) and the Soil Protection and Contaminated Sites Ordinance[20] (1999). In addition, there are the specific regulations of the federal states (as seen in section 2.2.3) and several guidelines and standard specifications, which are not legally binding, but necessary to accomplish the objectives of laws (as seen in section 2.3).

The Federal Water Act is the basic water law to regulate hydrologic balance and the supply and distribution of water. According to § 1 WHG the purpose of this law is the water management regarding the conservation of water as a part of the ecosystem, as the basis of human existence and as habitat for aquatic fauna and also water as a usable natural resource.

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[16] Grundgesetz, GG

[17] Wasserhaushaltsgesetz, WHG

[18] Abwasserverordnung, AbwV

[19] Bundesbodenschutzgesetz, BBodSchG

[20] Bunderbodenschutzverordnung, BBodSchV

Especially the third chapter “special terms of water management”, section 2 (sewage disposal) and section 3 (handling of water-hazardous substances), i. e. §§ 54 – 63 WHG, are important to highway runoff treatment. The § 54 WHG states that collected precipitation runoff from developed or paved areas is classified as wastewater. The disposal includes the collection, drainage, treatment, discharge, percolation and irrigation of wastewater. The § 55 (2) WHG promotes separate sewage systems by stating that precipitation runoff should be locally percolated, irrigated or drained and discharged into receiving waters without mingling with other (domestic, industrial) wastewater. In accordance with § 57 (1) WHG direct discharge of wastewater into receiving waters can only be permitted, if the quantity and noxiousness is as small as possible applying treatment facilities according to the state of the art. The discharge must be consistent with the water quality requirements.

Another important settlement is § 61, which regulates the self-monitoring obligation of wastewater treatment operators and will be discussed in chapter 6 of the present term paper.

The Wastewater Ordinance determines the minimum requirements for a regulatory permission to discharge wastewater into receiving waters as well as the measurement methods. Wastewater is considered specific to its source and branch. Several attachments, 57 in total, define the branch-specific parameters and limit values. The treatment of highway runoff is not specifically mentioned, since the ordinance refers mostly to industrial branches. Yet, the requirements generally apply for all wastewater treatment facilities. According to PFEFFERMANN (2011), an appropriate attachment has been in progress, but has not come to a result so far.

The Federal Soil Protection Act has the overriding objective of protecting soil from contamination and deterioration. Harmful soil changes need to be prevented, while contaminated sites need to be rehabilitated. Proper soil performance due to its functions in the ecosystem as well as the sustainable handling of soil must be provided. In the context of the Federal Soil Protection Act the natural good soil includes the unsaturated as well as saturated zone and soil liquefied by groundwater or percolation water.

The Soil Protection (and Contaminated Sites) Ordinance "specifies and supplies the Federal Soil Protection Act with provisions for implementation" and requirements for the rehabilitation of contaminated sites as well as the prevention of harmful soil changes. Requirements for the taking of samples and the analytic methods are specified and precautionary values as well as test values and action values are determined. [PFEFFERMANN, 2011]

These values are often applied when assessing percolation water samples to determine the quality and retention performance of soil or the contamination potential of percolated runoff.

Other laws that might be relevant for road drainage and highway runoff disposal are the Town and Country Planning Code [footer: Baugesetzbuch, BauGB], the Wastewater Charges Act[21] and the Nature Conservation Act[22].

2.2.3 Law of the federal states

The legal situation in the sixteen federal states concerning the subject 'management of stormwater on highways' is diverse. Although every state has its own water act, only some states effectively exert the opening clauses of the Federal Water Act and adopt their own specific laws on the treatment of stormwater, an ambit that has not been regulated to the full extend by the Federal Republic of Germany, while others solely refer to the given Federal laws [PFEFFERMANN, 2011].

Generally, every federal state water law demands the application of the best possible treatment methods for wastewater abatement. If stormwater resp. road runoff needs

[21] Abwasserabgabengesetz, AbwAG

[22] Bundesnaturschutzgesetz, BNatSchG

to be treated according to the federal state laws, the treatment facilities must regard the state of the art. Furthermore, in most state-own water acts percolation of untreated road runoff is to be avoided in water protection areas or catchment areas of drinking water wells and medicinal springs (which will not be specially mentioned for every concerned federal state).

There also are federal state regulations on the self-monitioring of highway runoff treatment facilities, which will not be discussed in this section, but in section 6.2 of this term paper, since these regulations refer specially to the topic of monitoring and cannot be listed as basic information.

Baden-Wurttemberg

The state-owned water act of Baden-Wurttemberg (LWG B-W)[23] was last amended in 2005 and generally promotes the decentralized percolation or abatement of stormwater. The treatment of loaded[24] stormwater, as well as wastewater in general, is a municipal obligation, but according to § 45b (2) LWG B-W this does not apply for the runoff from state or federal roads and highways. Also, § 45b (3) LWG Baden-Wurttemberg permits the ‘harmless’ percolation or the discharge of unloaded stormwater into nearby receiving waters for all land properties that were covered with buildings or pavement or in any other way connected to common sewage systems after 1999 without regulatory approval, given that the water quality of receiving waters will not be deteriorated by the discharge.

To achieve efficient stormwater management, the department of the environment Baden-Wurttemberg (UMBW) [Umweltministerium Baden-Württemberg] adopted a “Decentralized Stormwater Abatement Regulation”[25] in 1999, last amended in 2007. According to this regulation, stormwater can only be percolated or discharged into

[23] Landeswassergesetz Baden-Württemberg

[24] (mit Schadstoffen) belastet

[25] Verordnung des Umweltministeriums über die dezentrale Beseitigung von Niederschlagswasser Baden-Württemberg

receiving waters without further treatment, when it flows from roof areas (except industrial roof areas), built-up sites (except industrial or otherwise commercial used sites), roads (except carriageways with more than two lanes) or public sidewalks and bicycle lanes. Thus, highway runoff cannot be discharged or percolated without regulatory approval, respectively without preceding treatment. According to an administrative provision[26] of the department of the environment Baden-Wurttemberg and the internal affairs ministry for stormwater management, the discharge of such collected road runoff into receiving waters or groundwater inherently requires regulatory approval and must always be treated before discharge. If the stormwater is not collected, but immediately percolated over the embankments, it does not require approval, since the percolation over at least 30 cm of vegetated soil zone is considered as a nature-orientated treatment method [UMBW, 2007, § 2 (2)]. On account of these regulations, runoff from roads with a DTV exceeding 5000 motor vehicles per 24 hours is only collected, if the immediate percolation over the embankments is not possible for geologic, pedologic, topographic or constructive reasons.

In addition to the administrative provision for stormwater management the department of the environment Baden-Wurttemberg has adopted special regulations applying to water protection areas, which complement and adjust the regulations issued by the RiStWaG (2002) that will be discussed in section 2.3 (technical guidelines and standard specifications).

The selection of appropriate treatment facilities is performed according to another technical guideline, the advisory leaflet DWA-M 153 provided by the DWA[27], which will also be listed in section 2.3 and discussed in chapter 4 of this term paper.

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[26] Verwaltungsvorschrift

[27] German association for water management, waste and wastewater, German: Deutsche Vereinigung für Wasserwirtschaft, Abfall und Abwasser

Bavaria

The Bavarian Water Act[28] (BayWG, 2010) basically draws upon the regulations issued in the Federal Water Act. The section on wastewater abatement (article 34 BayWG) refers to § 56 of the Federal Water Act and defines the responsible bodies for wastewater treatment. Like in Baden-Wurttemberg wastewater abatement is a municipal obligation, excluding highways and state/federal roads.

The free state of Bavaria as adopted special regulations on stormwater management in the “Stormwater Exemption Ordinance” (NWfreiV)[29] (2000), which is dedicated to harmless percolation of collected stormwater that does not require regulatory approval, and the “technical regulations for harmless discharge of collectes stormwater into receiving waters” (TRENOG)[30]. The latter is not legally binding, but yet necessary to fulfill the regulations set by the BayWG, NWfreiV or the Federal Water Act.

According to § 2 NWfreiV runoff from roads with more than two lanes or roads that require plan approval procedures [footer: Planfeststellungsverfahren] is not to be percolated untreated. Additionally it is not permitted to discharge collected runoff from roads with a DTV exceeding 5,000 motor vehicles per 24 hours untreated into receiving waters, due to section 3 TRENOG.

Berlin

According to the state-owned water act of Berlin[31], last amended in 2005, the water and wastewater service of Berlin[32] is in charge of the abatement of runoff from public roads. In addition to the water act the senate administration of the city state Berlin

[28] Bayrisches Wassergesetz

[29] Niederschlagswasserfreistellungsverordnung

[30] Technische Regeln zum schadlosen Einleiten von gesammeltem Niederschlagswasser in oberirdische Gewässer

[31] Berliner Wassergesetz

[32] Berliner Wasserbetriebe, BWB

has released a “Stormwater Exemption Ordinance Berlin” (NWfreiV)[33] (2001) along with a comprehensive brochure about the dealings with stormwater.

Since Berlin is a communal estate (i. e. city state) and an agglomeration area Berlins surface area is paved or built-up to a great extend, which results in diminished groundwater recharge. Therefore the state of Berlin aspires to the harmless percolation of stormwater not only for public surface areas, but also for private persons. The brochure, which addresses the citizens of Berlin, advertizes the harmless percolation and introduces a new scale of fees and charges that remits stormwater drainage charges[34] partially or entirely, if a considerable amount of stormwater is percolated on the premises. For the selection of appropriate facilities to percolate stormwater the recommendations of the worksheet ATV-DVWK-A 138, which will be looked at in section 2.3, apply [BERLIN SENATE ADMINISTRATION, 2001].

According to § 2 NWfreiV collected runoff from roads with a DTV exceeding 500 motor vehicles per 24 hours cannot be discharged untreated into receiving waters. The discharge of loaded road runoff acquires a regulatory approval. The requirements to treatment derive from the Federal Water Act and the Wastewater ordinance [BERLIN ENVIRONMENT, URL; 02/14/2012]

Brandenburg

The federal state of Brandenburg has adopted a state-own water act[35] (BbgWG) in 1994, which was last amended in 2004. According to § 54 (4) BbgWG unloaded stormwater and runoff from public traffic areas can be percolated, given that no harmful effects on groundwater are expectable. The local authorities can adopt statutes that compel citizens to percolate collected stormwater on the premises. Also, the ministry for environment, health and consumers protection Brandenburg[36] has

[33] Niederschlagswasserfreistellungsverordnung

[34] Regenwasserableitungsgebühren

[35] Brandenburgisches Wassergesetz

[36] Ministerium für Umwelt, Gesundheit und Verbraucherschutz

released a guideline for nature-orientated handling of stormwater, which gives information about several stormwater treatment methods and requirements.

The BbgWG does not state a daily traffic volume, above which road runoff must be treated. Yet, the definition of wastewater, basically drawing upon the statements of the Federal Water Act, includes runoff from paved and built-up areas. According to PFEFFERMANN (2011) the percolation of runoff from roads with a DTV lower than 2,000 motor vehicles per 24 hours can be tolerated.

Bremen

§ 132a BremWG (Bremen Water Act[37]) from 2004 promotes the preference of decentralized stormwater abatement, meaning harmless percolation or discharge of unloaded stormwater in nearby receiving waters, given that the drained area does not exceed 1,000 m^2.

Polluted runoff from highly frequented traffic areas should be percolated through at least 30 cm of vegetated top soil (resp. the embankments). If the runoff cannot be percolated decentralized and has to be discharged, it must be treated beforehand. [PFEFFERMANN, 2011]

Hamburg

The Hamburg Water Act[38] (HWaG) does not make specific statements on the treatment of stormwater. Only § 32b names the disclosure duty for percolation of stormwater on the premises. [HWAG, URL; 02/18/2012] The Hamburg Wastewater Act[39] (HmbAbwG) effectively takes over the wastewater definition from the Federal Water Act, but excludes road runoff treatment facilities from the public wastewater treatment plants that are subject to the law [§ 1 (4) clause 3 HmbAbwG].

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[37] Landeswassergesetz Bremen

[38] Hamburgisches Wassergesetz, 2005

[39] Hamburgisches Abwassergesetz, 2001

However, the city administration of the communal estate of Hamburg has addressed the topic stormwater treatment. The authority for city development and environment[40] has released a brochure about the handling of stormwater, according to which runoff from roads with a DTV of more than 15,000 motor vehicles per 24 hours should, if possible, be percolated extensively over the embankments. If it must be drained and collected it cannot be discharged without preceding treatment. According to PFEFFERMANN (2011) runoff from roads with a DTV of more than 15,000 motor vehicles per 24 hours are classified as heavily polluted and require additional cleaning stages (f. e. filtration stages) to the usual mechanical treatment.

Hesse

Similar to the Hamburg Wastewater Act the definition of wastewater by the Hessian Water Act[41] (HWG) is taken over from § 54 Federal Water Act. According to § 37 HWG wastewater abatement is a municipal obligation, which does not apply for runoff from public roads.

Apart from the Hessian Water Act there were no specific regulations or guidelines on stormwater handling or treatment of road runoff to be found.

Mecklenburg-West Pomerania

The state-own water act of Mecklenburg-West Pomerania[42] (LWaG) states regulations almost identical to the Hessian regulations. According to § 40 LWaG wastewater abatement is a municipal obligation, which does not apply for runoff from public roads. Apart from the state-own water act of Mecklenburg-West Pomerania specific regulations or guidelines on treatment of road runoff could not be found.

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[40] Behörde für Stadtentwicklung und Umwelt der Hansestadt Hamburg

[41] Hessisches Wassergesetz, 2010

[42] Landeswassergesetz Mecklenburg-Vorpommern, 2010

According to PFEFFERMANN the recommendations and regulations, which will be discussed in section 2.3, are applied in Mecklenburg-West Pomerania.

Lower Saxony

The water act of Lower Saxony determines no specific regulations on stormwater treatment resp. the treatment of road runoff. The authority for water management and coastal and environmental protection of Lower Saxony[43] (NLWKN) gives recommendations on the utilization of stormwater, but refers rather to drinking water and process water [NLWKN, URL; 02/18/2012]. Road runoff treatment is not mentioned and further data are not available.

Northrhine-Westphalia

§ 51a of the Northrhine-Westphalian water act[44] (LWG) of 1995 declares that stormwater should be percolated decentralized or discharged into nearby receiving waters, given that nor harmful effects on the water body or the environment is to be expected. The ways and means of stormwater treatment can be determined by communal statutory. The ministry of climate and environmental protection, agriculture and consumers protection Northrhine-Westphalia (former ministry of environment, land use regulation and agriculture) has also enacted a circular decree on “stormwater disposal pursuant to § 51a LWG” in 1998 and another circular decree on “requirements for precipitation drainage in the separation system” in 2004. According to annex 1 of the latter decree runoff from highly frequented roads like highway is classified as highly polluted. At least medium loads of MOTH[45], heavy metals and organic pollutants must be expected. Highly polluted precipitation runoff must be collected and lead to a treatment facility. Possible treatment methods are listed in the annex 2.

[43] Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Umweltschutz

[44] Landeswassergesetz Nordrhein-Westfalen

[45] Mineral oil-type hydrocarbons

In addition to that the authority for road construction of Northrhine-Westphalia[46] has released a planning guide on road drainage and water protection[47] in 2011, which is used as an “internal working tool regarding the treatment of road surface water” [PFEFFERMANN, 2011]. It provides detailed regulation and recommendations on road drainage and runoff treatment, regarding design and building of treatment facilities, applied technologies, the state of the art and the consideration of recommendations like the DWA-leaflets. According to section 1.1 the planning guide draws upon the regulations of the RAS-Ew and RiStWag.

Rhineland-Palatinate

The water act of Rhineland-Palatinate[48] (LWG) of 2011 is, like most federals states, closely orientated towards the federal Water Act. No specific regulations on road runoff are stated. Nevertheless, supra-regional roads with more than two lanes are excluded from the ‘harmless percolation’ of runoff according to § 36 (4) LWG.

The ministry of environment, agriculture, alimentation, viniculture and forestry Rhineland-Palatinate[49] (MULEWF) has released a brochure on nature-orientated dealings with stormwater, which contains the stormwater concept, recommendations and practical examples. Yet, the topic of road runoff treatment is not addressed specifically.

[46] Landesbetrieb für Straßenbau Nordrhein-Westfalen

[47] Planungsleitfaden Straßenentwässerung und Gewässerschutz

[48] Landeswassergesetz Rheinland-Pfalz

[49] Ministerium für Umwelt, Landwirtschaft, Ernährung, Weinbau und Forsten Rheinland-Pfalz

Saarland

The water act of Saarland[50] (SWG) of 2007 determines that stormwater should be utilized, percolated or irrigated on the premises, whenever possible. Similar to the regulations of Lower Saxony the implementation of stormwater treatment can be determined by communal statutory. According to § 49a (4) SWG stormwater, which is mingled with domestic or other wastewater in a combined sewage system is excluded from this obligation. Newly built drainage facilities should built according to the separate sewage system.

In addition to the water act there are some local authorities that released brochures on stormwater utilization, f. e. the city of Sulzbach. These brochures are not relevant to the dealings with road runoff, since they refer to the percolation of stormwater on the premises, the collection and utilization as process water or the preparation as drinking water [SULZBACH MUNICIPAL WORKS, no year].

Saxony

The watewater definition of the water act of Saxony[51] (SächsWG) as well as the exclusion of runoff from non-local roads from the municipal wastewater abatement obligation is similar to other federal states. The SächsWG does not appoint special regulations on road runoff treatment.

The Saxon state ministry of environment and agriculture adopted an ordinance on the exemption of concession for designated groundwater utilization[52] (ErlFreihVO) in 2001. It states the types of precipitation runoff that can be percolated or discharges without further treatment due to origin or branch. Runoff from supra-regional roads is excluded. [SAXONY, URL; 02/18/2012]

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[50] Saarländisches Wassergesetz

[51] Sächsisches Wassergesetz, 2004

[52] Verordnung des sächsischen Ministeriums für Umwelt und Landwirtschaft über die Erlaubnisfreiheit von bestimmten Benutzungen des Grundwassers

Saxony-Anhalt

§ 69 of the WGL SA[53] (water act of Saxony-Anhalt) relates to § 46 of the Federal Water Act and regulates under which conditions groundwater utilization can be permitted without regulatory approval. § 69 (2) WGL SA states that the ministry in charge of water management can devolve the determination of the requirements for harmless percolation unto the water authorities. Further regulations on stormwater management are not given.

Schleswig-Holstein

The water act of Schleswig-Holstein[54] (WasG SH) of 2008 is, like most federals states, closely orientated towards the federal Water Act. No specific regulations on road runoff are stated.

As long ago as 1992 the ministry of agriculture and environment Scheswig-Holstein has issued “technical regulations for the construction and operation of stormwater treatment facilities in separate sewage systems”[55] that apply in addition to the WasG SH. Precipitation runoff that is discharged out of separate sewage systems into receiving waters generally must be treated beforehand. Section three of the technical regulations specifies the properties of stormwater and classifies precipitation runoff regarding its origin. According to section 3.2 of the technical regulations runoff from highly frequented roads[56] is classified as ‘medium loaded’. And therefore must be treated at least in a stormwater sedimentation tank. There is no explicit classification of highway runoff. [STATE GOVERNMENT SH, URL; 02/19/2012]

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[53] Wassergesetz des Landes Sachsen Anhalt

[54] Wassergesetz Schleswig-Holstein

[55] Technische Bestimmungen zum Bau und Betrieb von Anlagen zur Regenwasserbehandlung bei Trennkanalisation

[56] hier: Hauptverkehrsstraßen, nicht näher definiert

Thuringia

The water act of Thuringia[57] (ThürWG) states that stormwater should, whenever possible, be percolated decentralized on the premises. In addition to the ThürWG the ministry of agriculture and environment Thuringia issued a directive on “harmless percolation of stormwater, which does not require regulatory approval”[58] (ThürVersVO). Runoff from highly frequented roads is excluded in this directive.

According to PFEFFERMANN (2011) runoff from roads with a DTV less than 2,000 motor vehicles per 24 hours can be discharged untreated, if no harmful effects on envoronemnt or water bodes can be expected. This regulation refers to the RAS-Ew.

2.3 Technical guidelines and standard specifications

Technical guidelines and standard specifications are recommendations and proposals from professional bodies[59], organizations and committees to fulfill the requirements given by law. They can be legally binding if laws and ordinances built upon the regulation recommendations given by guidelines and standard specification. However, it is mostly advisable to operate under these specifications, unless laws or ordinances (which are legally binding) have issued different regulations.

2.3.1 ISO / EN / DIN standards

ISO, EN or DIN standards are the result of international, European or national standardization work. They are implemented by the prevailing committees of the International Standardization Organization (ISO) for international standards, the European Committee for Dtandardization (CEN) for European standards and the

[57] Thüringisches Wassergesetz

[58] Thüringer Verordnung über die erlaubnisfreie schadlose Versickerung von Niederschlagswasser

[59] Berufsverbände

German Institute for Standardization[60] (DIN) for national (German) standards. [PFEFFERMANN, 2011]

These standards are not legally binding. Yet, they substantiate and specify the requirements given by the law. Since it can be assumed that anyone in charge of a production or construction site complies with the law when applying the (ISO/EN) DIN standards, the standards provide legal security to a high extend. [DIN, URL; 02/19/2012]

The most important standard for the discharge of highway runoff is the DIN 1986-3, which is derived from the DIN EN 752 and DIN EN 12056, a set of standards addressing the drain and sewer systems of buildings and premises. Another standard that might be relevant to highway runoff treatment is the DIN 1999-1000, which is derived from the DIN EN 858 and is concerned with installations for the separation of light liquids. [NAW DIN, URL; 02/19/2012]; [PFEFFERMANN, 2011]

2.3.2 RAS regulations

The RAS[61] regulations on road construction are issued by the Research Society for Road and Transportation[62] (FGSV), a non-profit-making technical and scientific association that aims to continuously develop technical knowledge and improvement in the road and transportation sector. [FGSV A, URL; 02/19/2012]

The RAS-Ew[63] (2005) provides standards for the design and construction of road drainage systems.

According to RAS-Ew runoff from roads with a DTV exceeding 2,000 motor vehicles per 24 hours should be treated. This treatment includes extensive percolation over the embankments or in seepage pits for road runoff. The vegetated top soil should

[60] Deutsches Institut für Normung

[61] Richtlinien für die Anlage von Straßen

[62] Forschungsgesellschaft für Staßen- und Verkehrswesen

[63] Richtlinien für die Anlage von Straßen – Teil: Entwässerung

have a thickness of approx. 20 cm, while an embankment steeper than 1:2 requires a thickness of only 10 cm of vegetated top soil. The hydraulic permeability necessary to a certain clearing effect varies from k_f = 10 – 3 m/s to k_f = 10 – 5 m/s. If extensive percolation is not possible on account of the hydrologic, geological, ecological or structural conditions the runoff must be collected and supplied to an appropriate treatment and percolation system. Possible percolation facilities are troughs, trenches, seepage reservoirs or retention soil filters. Stormwater sedimentation or settling tanks and light liquid separators should preferably be installed upstream. [RAS-Ew, 2005, section 1.2.3, 1.3.2, 7.2; quoted by PFEFFERMANN, 2011]

The guidelines[64] of the DWA (see also section 2.3.3 of this term paper) supplement the RAS-Ew with more specific regulations on the appropriate treatment methods and in which case to apply them. [PFEFFERMANN, 2011]

According to the FGSV the RAS-Ew is currently reconsidered. At present the RAS-Ew unintentionally competes with the regulations of the DWA in plan approval procedures. Revisions could be made by bringing the RAS-Ew more in line with the DWA guidelines and to constitute deviations from the DWA regulations more precisely. [FGSV B, URL; 02/19/2012]

The „guidelines for structural measures on roads in water protection areas" (RiStWag[65], 2005) applies to the planning, construction and fitout of roads in water protection areas as well as in areas serving the public water catchment [RISTWAG, 2002 section 1]. According to section 6.2.6 RiStWag the choice of an appropriate drainage system depends on the traffic intensity, the vulnerability of the respective protection zone and the protective effect of the groundwater covering.

[64] hier: Regelwerk

[65] Richtlinie für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten

	Protection zone III or III A Protective effect of groundwater			Protection zone III B Protective effect of groundwater		
DTV [vehicles/d]	**high**	**medium**	**low**	**High**	**medium**	**Low**
< 2,000	Level 1	Level 2	Level 2	Level 1	Level 1	Level 2
2,000 – 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

Level 1	Extensive percolation over the vegetated top soil (soil properties should be regulated by ATV-DVWK-A 138, see also section 2.3.3), trenches, troughs or percolation tanks.
Level 2	Extensive percolation over the vegetated top soil, trenches or troughs. Percolation tanks are only permitted with upstream settling facilities.
Level 3	Road runoff is collected (road gullies and high-edged curbs), drained in dense pipes, sealed trenches or channels and discharged outside the ambit of the protection zone.
Level 4	In addition to the provisions from level 3 the embankments should be sealed.

Tab. 2: Classification of discharge measures in the water protection zone III [RiStWag, 2002]

Water protection zone II requires further provisions against pollution. The percolation of road runoff is generally prohibited. Like in Level 4 (table 2) road runoff must be collected and drained out of the water protection area in dense pipes and sealed gutters. Also, the embankments must be sealed. To prevent harm from traffic accidents the embankments should be built more broadly in the water protection zone II. Groundwater can on no account be modified; the dissection or lowering of the groundwater table is not permitted

If the road runoff must be discharged into receiving waters within the ambit of water protection zones (which is generally to be prevented), the flow direction of the receiving water as well as the daily traffic volume of the road decide on the treatment measures. If the DTV exceeds 2,000 motor vehicles per day, the runoff cannot be discharged untreated, unless water authorities charter exceptional permission. [RISTWAG, 2002 sections 6.2, 6.2 and 6.4]

2.3.3 DWA advisory leaflets and worksheets (ATV-DVWK)

The German association for water management, waste and wastewater (DWA) originates from the ATV-DVWK, an incorporation of the two professional associations “wastewater engineering association”[66] (ATV) and the “German association for water management and land improvement”[67] (DVWK). Thus, literature references and sources that were published around 2004 still employ the term ‘ATV-DVWK Leaflets’, which are the same as the DWA Leaflets.

The DWA is a technical and scientific professional association that has adopted a wide range of guidelines[68] on urban water management containing advisory leaflets[69] and worksheets[70]. These regulations are generally accepted as a basis for the planning, constructing and operating of water and wastewater management facilities [PFEFFERMANN, 2011]. The four leaflets/worksheets most important to highway runoff treatment are introduced in the following.

The DWA worksheet A 138 (2005) is dedicated to the “planning, construction and operation of facilities for the percolation of precipitation water” [PFEFFERMANN, 2011]. The antecedent worksheet was adopted by the ATV in 1990 and contributed significantly to the rethinking-process on combined sewage systems and thus to the promotion of separate sewage systems. The worksheet DWA-A 138 provides information for planners, building contractors and authorities about contemporary reliable measurements and facilities for the percolation of stormwater that is drained

66 Abwassertechnische Vereinigung e.V.

67 Deutscher Verband für Wasserwirtschaft und Kulturbau e.V.

68 hier: Regelwerk

69 Merkblätter (M)

70 Arbeitsblätter (A)

from water permeable and non-permeable developed or otherwise fixated surfaces. [DWA-A 138, 2005]

Several percolation methods are discussed in the DWA-A 138 [PFEFFERMANN, 2011]:

(a) Extensive percolation
(b) Trough percolation
(c) Trough-trench percolation
(d) Trench and pipe-trench percolation
(e) Shaft percolation
(f) Tank percolation
(g) Trough-trench systems

Runoff from different areas (origins) is categorized as ‘harmless’ (resp. uncritical), tolerable and non-tolerable according to its pollution loads (resp. the expectable pollutant ingress). For the assessment of harmful effects on groundwater resulting from road runoff the DTV is a relevant factor. Table cde shows a traffic-related excerpt of table 1 of the DWA-A 138 in reference to the treatment methods listed above.

		Above-ground percolation methods			Below-ground percolation methods	
DTV [vehicles/24h]	Category	(a)	decentralized (b) , (c)	centralized (b), (f)	(d)	(e)
< 300	Tolerable	+	+	(+)	(-)	-
300 – 5,000	Tolerable	+	+	(+)	(-)	-
5,000 – 15,000	Tolerable	+	+	(+)	-	-
> 15,000	Tolerable	+	(+)	(+)	-	-

+	Permissible
(+)	permissible with upstream treatment (f. e. according to DWA-M 153)
(-)	only permissible with exceptional permission (individual case assessment)
-	not permissible

Tab. 3: Percolation of precipitation runoff from different traffic areas [deduced from DWA-A 138, table 1]

Table 3 clearly shows that decentralized above-ground percolation should be preferred according to DWA-A 138.

The DWA leaflet M 153 (2000) provides planning aid for the selection of appropriate measurements and facilities for the treatment of percolation runoff that should be applied for simple water conditions and separate as well as modified sewage systems, especially in road drainage. The contamination of runoff is evaluated along with the local water conditions and the effectiveness of treatment methods in a scoring system [UHL, GROTEHUSMANN, no year]. Table 4 shows this scoring system according to DWA-M 153 [quoted by UHL, GROTEHUSMANN, no year].

Pollution load from the area			
Contamination	**Exemplary origin areas**	**Type**	**Points**
Low	Green roofs	F1	5
	Roof (excluding roof surfaces with copper, zinc or lead parts) and terrace surfaces from residential areas and comparable commercial areas	F2	8
	Bike lanes and sidewalks in a distance of more than 3 meters from roads	F3	12
	Yard and car parking areas without frequent change of vehicles in residential areas and comparable commercial areas		
	Scarcely used traffic areas with a DTV of less than 300 vehicles/24h in residential areas and comparable commercial areas		
Medium	Roads with a DTV of 300 – 5,000 vehicles/24h	F4	19
	Yard and car parking areas without frequent change of vehicles in mixed, commercial and industrial areas (excluding reloading points and terminals)	F5	27
	Roads with a DTV of 5,000 – 15,000 vehicles/24h		
High	Car parking areas with frequent chance of vehicles	F6	35
	Highly polluted roads and squares		
	Roads with a DTV exceeding 15,000 vehicles/24h		
	Highly frequented truck access roads in commercial, industrial or comparable areas	F7	45*
	Truck parking areas		

Tab. 4: Evaluation points for the contamination categorized by the origin of runoff; excerpt from the scoring system according to DWA-M 153; quoted by UHL, GROTEHUSMANN, no year
* Percolation only allowed with control option after cleaning

The practical and mathematical selection of an appropriate treatment system by the DWA-M 153 will be shown in section 4.1 of this term paper.

The DWA worksheet A 166 (1999) is concerned with “buildings for the central stormwater treatment and retention” and aims to assist planners, building contractors and authorities with the planning, construction and equipment of centralized treatment facilities for precipitation runoff regarding technical, operational and economic aspects.

According to PFEFFERMANN (2011) the regulation s of the DWA-A 166 comprise buildings of centralized stormwater treatment and retention in the combined as well as in the separate sewage system. This means stormwater overflow tanks and sewers with storage capacities and overflow in the combined system and stormwater sedimentation tanks in the separate system. Stormwater holding tanks and retention soil filters are part of the combined as well as the separate sewage system. Open building methods for separation systems are preferable due to the ease of maintenance, the costs incurred and the good environmental integration. Also, systems without permanent storage should be preferred. [PFEFFERMANN, 2011]

The DWA leaflet M 178 (2005) provides “recommendations for planning, construction and operation of retention soil filters for further stormwater treatment in the combined and separate sewage system”. It basically outlines the practical experiences that were made with the dimensioning, designing and operation of retention soil filters.

According to PFEFFERMANN (2011) the DWA-M 178 prefers open building methods for retention soil filters. Two-stage systems with upstream stormwater sedimentation tanks and downstream retention soil filter are preferable.

2.3.4 BWK leaflets

The German "association of engineers for water management, waste management and land improvement"[71] (BWK) is a professional association that supports "science, research, education and environmental protection in the fields of water management, soil protection, remediation of contaminated sites and land improvement." [PFEFFERMANN, 2011]

Similar to the DWA the BWK has adopted a set of leaflets containing technical recommendations to stormwater treatment. The most important BWK leaflet for road runoff treatment is the BWK-M 3 (2007) that develops "immission-orientated requirements for combined wastewater and stormwater discharge with consideration of the local conditions". Recommendations for the assessment of the impact of combined wastewater and stormwater discharge on the receiving waters and possible actions are proposed. According to PFEFFERMANN (2011) the examined parameters are Q (quantity), NH_4-N (ammonium nitrate), TSS (total suspended solids) and BOD_5 (biological oxygen demand).

[71] Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau

3. Highway runoff treatment

This chapter is dedicated to the treatment of highway runoff. In the first section (3.1) highway runoff water will be described and relevant compounds as well as their sources and accumulation will be discussed. Also, traffic-related priority hazardous substances of the European Water Framework Directive and their properties will be looked at. The second section (3.2) gives an overview on the current treatment methods (state of the art) and possible best practice methods for the elimination of priority hazardous substances.

3.1 Highway runoff water

Traffic generates a wide range of pollutants that can be hazardous to human health by directly affecting the organisms[72] or by impairing natural goods such as biospheres, habitats and natural resources like water and soil. Especially runoff from highly frequented roads bears significant loads of pollutants that, if discharged untreated into receiving waters, can deteriorate water quality and not only threaten aquatic organisms, but also water resources like groundwater, which are used for drinking water production. Depending on particle diameters, water solubility of the substances and the depth to water table percolation of highway runoff through the soil can affect groundwater as well.

[72] by skin contact or by inhaling of polluted air

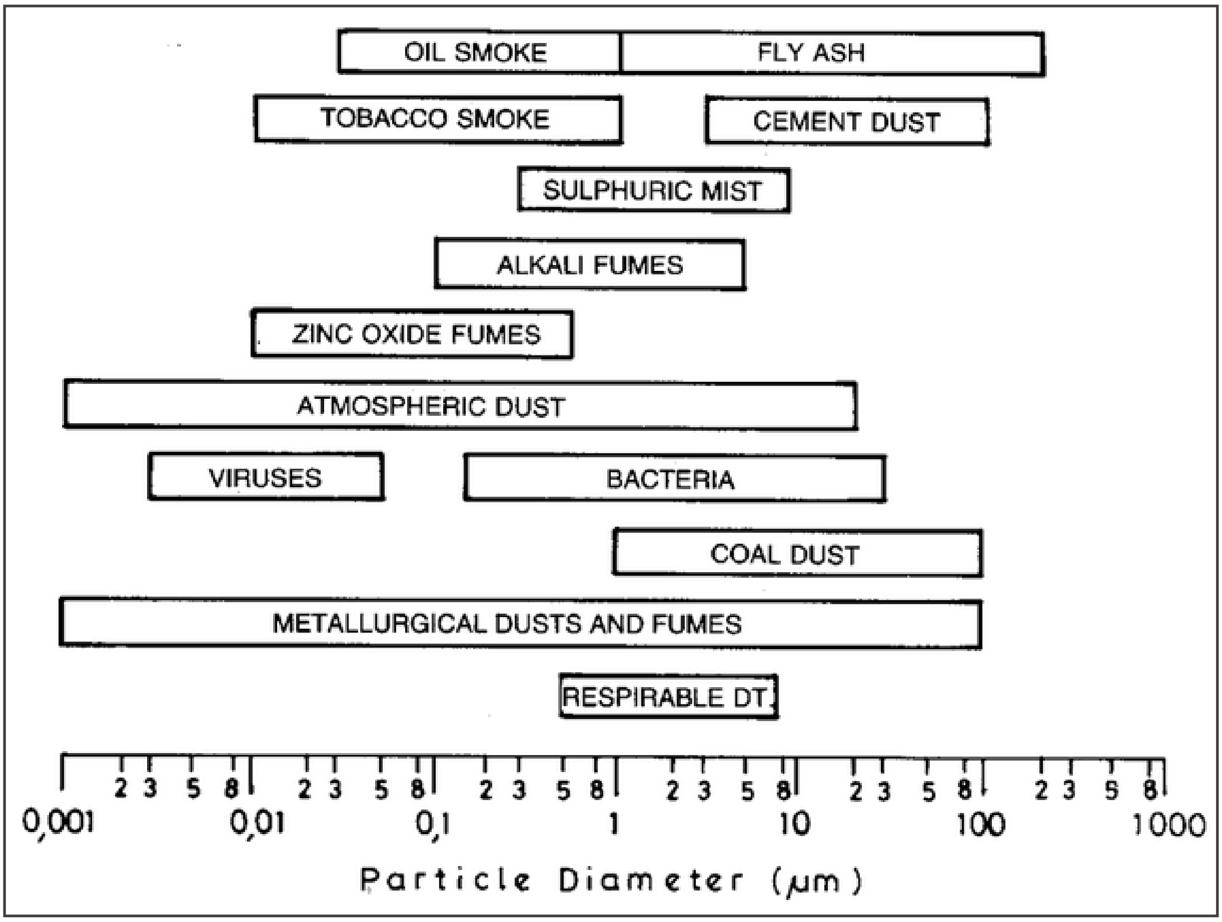

Fig. 6: Logarithmic chart of size ranges of some common particles [KUHN, URL; 02/04/2012]

Generally, well degradable substances have less harmful effects on the environment than persistent pollutants. Substances with minor water solubility mostly accumulate in the soil passage and do not reach groundwater. In case of heavy rainfall and the resulting erosion these substances can nevertheless be washed away and find their way into water bodies. Water-hazardous substances primarily are slightly soluble substances in solid, liquid or gaseous aggregate phase, since they are able to deteriorate the physical, chemical or biological properties of water. [RISTWAG, 2002]

3.1.1 Accumulation process and washout

Pollutants (directly resulting from traffic or from atmospheric preloads) settle on the road surface as dust (dry deposition) or are directly washed out of the air by precipitation (wet deposition) [KUMMER, no year]. Precipitation water flows almost entirely off the roadway[73] and carries pollutants with it, either in the form of suspended particles or dissolved. A popular view on the accumulation process says that the duration of dry weather periods is crucial to the amount of pollutants that accumulate on the road surface and that heavy rainfall clears large amounts of pollutants from the surface [WINKLER, 2005]. In the consequence, the highway runoff has ‘first flush characteristics’, which means that the highest pollutant concentrations and the major part of the pollution load can be found in the runoff water collected throughout the first stages of a storm event. This effect also applies to the mobilization of solids and pollutants that accumulated in gutters. Other researches[74] found that storm events usually only remove minor parts of the pollutant load from the road surface. In fact, the duration and intensity of the precipitation as well as the decomposition, solution and transformation of highway runoff compounds under the influence of precipitation water, which are part of the removal process of pollutants, are more important.

Figure 7 shows the accumulation and washout process of atmospheric pollution expressed in an exponential curve, limited by a maximum value (P_{max}) and a minimum value (P_{min})” [Sieker, Grottker, 1998; quoted by WINKLER, 2005]. The following figure 8 shows the same process for pollutants on road surfaces.

[73] run-off coefficient of pavement: 0.9, i. e. 90 % discharge

[74] Malmquist (1978), Chiew, Duncan and Smith (1997), Chiew and Vaze (2000); quoted by WINKLER, 2005

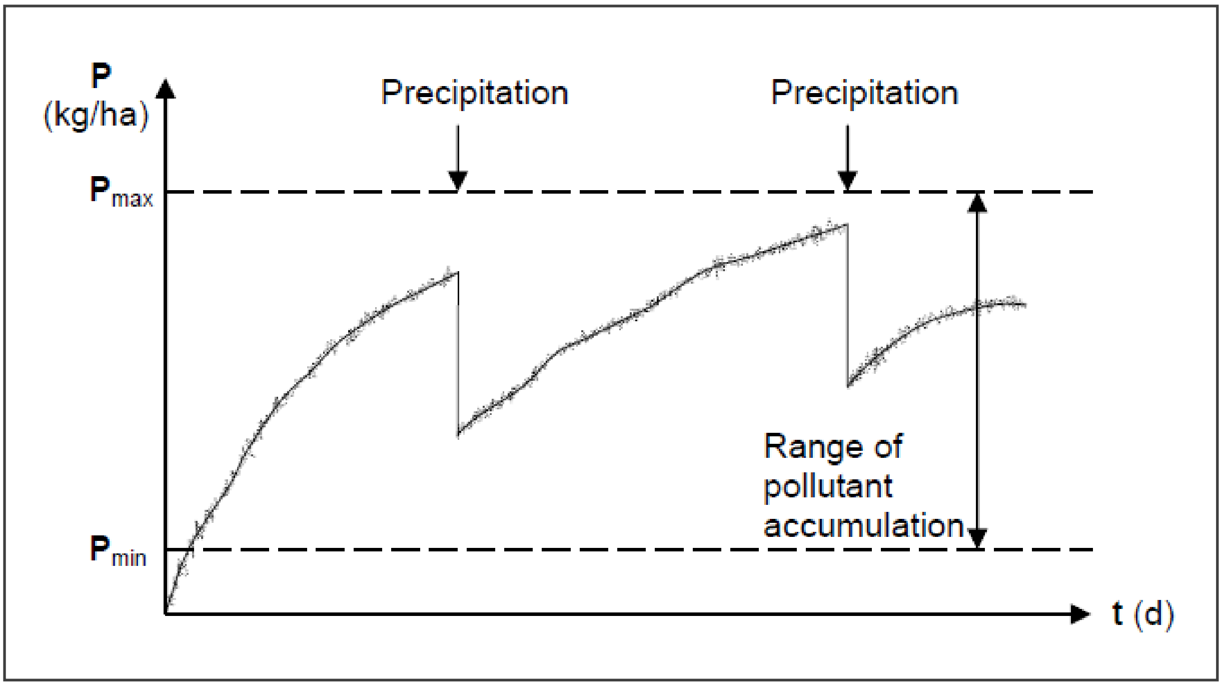

Fig. 7: Accumulation and washout of atmospheric pollutants
[Sieker, Grottker, 1998; quoted by WINKLER, 2005]

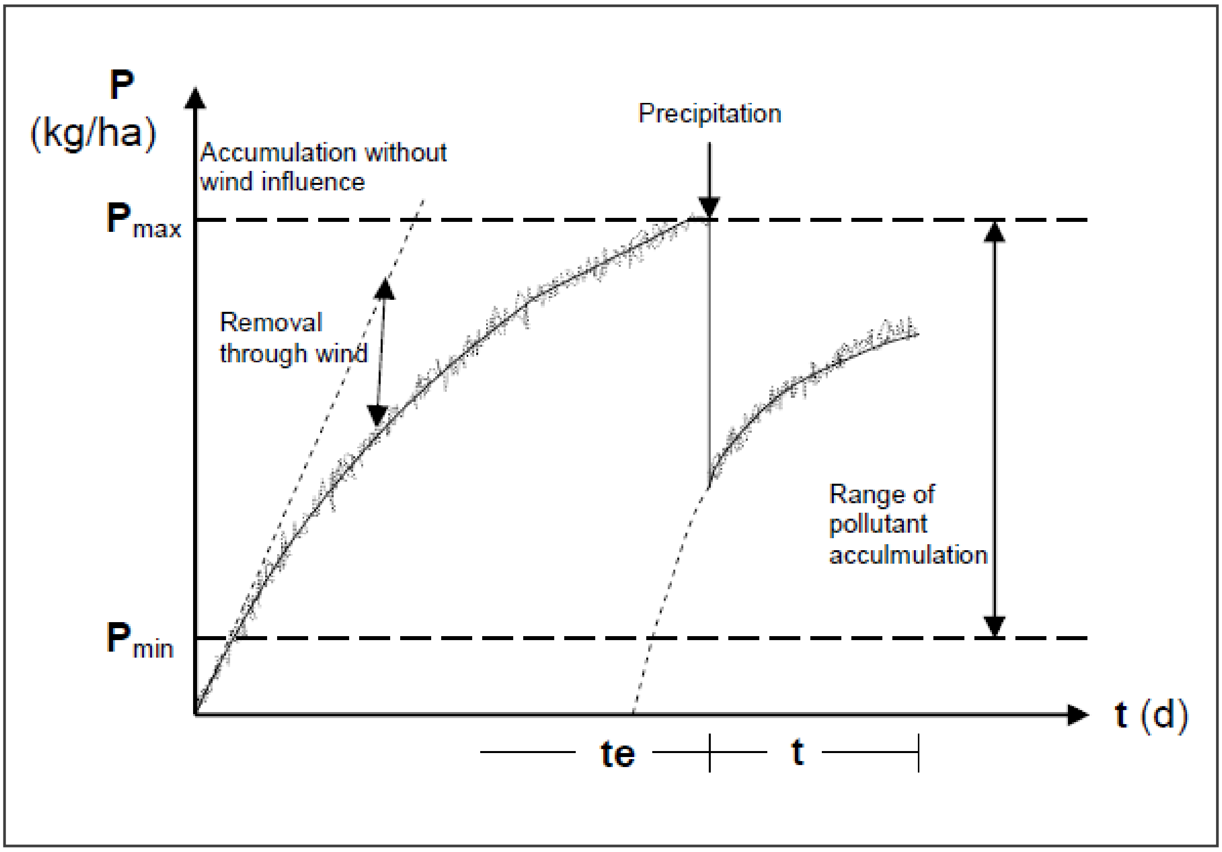

Fig. 8: Accumulation and washout of pollutants on the road surface
[Sieker, Grottker, 1998; quoted by WINKLER, 2005]

3.1.2 Pollutant categories and sources

Research projects and surveys[75] have revealed several categories of pollutants commonly occurring in highway runoff [modified according to HERRERA, 2007]:

- Nutrients
- Heavy metals
- Suspended solids
- Oxygen-consuming substances
- Organic pollutants
- Pathogens (bacteria and viruses)

Some parameters out of those categories are already part of standardized water quality[76] surveys. Apart from conventional parameters like oxygen content, hardness, conductivity or pH-value pollutants like oxygen-consuming substances (f. e. BOD_5, COD), nutrients (phosphorus and nitrogen compounds) and suspended solids are relevant parameters to determine the water quality in rivers, streams and lakes. In addition to that, water-hazardous substances like heavy metals are most frequently reviewed in the course of environmental monitoring. Also, total suspended solids are mostly reported in highway runoff, since heavy metals and noxious organic compounds are often bound to fine particles [HERRERA, 2007].

[75] KOCHER and BEER (2007), KOCHER (2011), WINKLER (2005), HERRERA (2007)

[76] hier: Gewässergüte

Pollutant category	**Relevant parameters in highway runoff**
Nutrients	Ammonia nitrogen (NH_4-N) Nitrate nitrogen (NH_3-N) Total nitrogen (N_{tot}) Total phosphorus (P_{tot}) Orthophosphate phosphorus (H_3PO_4-P)
Heavy metals	Arsenic (As) Cadmium (Cd) Chromium (Cr) Copper (Cu) Iron (Fe) Lead (Pb) Mercury (Hg) Nickel (Ni) Zinc (Zn) Cobalt (Co)* Molybdenum (Mo)* Vanadium (V)*
Suspended solids	Total suspended solids (TSS) Volatile suspended solids
Oxygen-consuming substances	Biological oxygen demand up to 5 days (BOD_5) Chemical oxygen demand (COD) Total organic carbon (TOC)
Organic pollutants	Adsorbable organic halogen compounds (AOX) Total petroleum hydrocarbons (TPH)**

	Polycyclic aromatic compounds (PAH) Oil and grease Pesticides
Pathogens	Total coliform bacteria
Salts (when de-icing is performed)	Sodium (Na) Chloride (Cl)

Tab. 5: Pollutant categories and typical pollutants in highway runoff
[Modified according to HERRERA, 2007]
* Supplement: transition metals stated by KOCHER, 2007
**synonymic term used in this term paper and other sources: MOTH (mineral oil-type hydrocarbons)

The various sources of pollution by motor vehicle traffic are listed in the RiStWag as follows:

Pollution source	**Relevant parameters**
Exhaust fumes	Nitrogen oxides (NO_X) Carbon dioxide (CO_2) Carbon monoxide (CO) Carbon black (resp. soot) [containing carbon, lead, sulfur, chlorine, magnesium, sodium, copper, zinc] Manganese (Mn)* Polycyclic aromatic hydrocarbons (PAH) Phenoles Polychlorinated dibenzodioxins (PCDD) Polychlorinated dibenzofurans (PCDF)
Abrasion of road surfaces	Silicon (Si) Calcium (Ca) Magnesium (Mg) Chromium (Cr)

	Nickel (Ni) Asphalt particles [containing f. e. bitumen, minerals]
Abrasion of vehicle tires	Rubber particles* Carbon / Hydrocarbons Zinc (Zn) Sulfur (S) Chlorine (Cl) Iron (Fe) Silicon (Si) Magnesium (Mg) Copper (Cu) Lead (Pb) Cadmium (Cd)
Abrasion of brake lining	Asbest* Carbon / Hydrocarbons Zinc (Zn) Iron (Fe) Silicon (Si) Magnesium (Mg) Copper (Cu Sulfur (S) Nickel (Ni) Chromium (Cr) Barium (Ba) Titanium (Ti) Vanadium (V)
Materials of catalysts	Platinum (Pt) Rhodium (Rh) Palladium (Pd)

	Pesticides, PCB*
Drip losses	Oil Fuel [Chloride*, Sulfate*, Nickel*, PAH*] Brake fluid De-icing fluid Greases Underseal agent Detergents Preservatives Losses from animal transportation* [BOD_5*, COD*]
Evaporation losses	Hydrocarbons
Corrosion products	Iron (Fe) Cadmium (Cd) Copper (Cu) Zinc (Zn)
De-icing salts*	Bromide (Br)* Cyanide (HCN-compounds)* Sodium (Na) Calcium (Ca) Chloride* Sulfate*

Tab. 6: Pollution sources and parameters [RiStWag, 2002]
* Supplement: sources and relevant parameters stated by Winkler, 2005

In addition to that, some of the compounds of highway runoff do not directly result from traffic, but from atmospheric preloads, which depend on the land use of the surroundings. For example, nutrients like oxides of nitrogen and phosphorus often result from the use of fertilizers in agriculture and are wafted on the road surface bound to dust particles. The same applies to pathogens, which can result from agriculture and be brought to road surfaces in the form of aerosols.

In agglomeration areas atmospheric preloads contain a wide range of pollutants that can result directly from traffic, but also from industry or domestic emission (f. e. stoves) like carbon dioxide, carbon monoxide, sulfur dioxide, oxides from nitrogen, polycyclic aromatic compounds, petroleum hydrocarbons or heavy metals. Oxygen demanding organic substances (BOD_5) are no standard compounds in urban atmospheric preload. [KUMMER, no year]

Some studies, as quoted by WINKLER (2005), conclude that organic compounds in highway runoff are found more often in urban than in rural areas, since waste, roadside plants and leafs tend to remain on the road surface at a greater extend. Yet, contrary to that and to the data stated in table fgh, oxygen demanding compounds and nutrients are no essential or decisive compounds of highway runoff water according to DWA and DBU (2010). Also, pathogens (especially fecal coliform bacteria[77]) are rather untypical[78] compounds of urban highway runoff and more often found in domestic wastewater. Available data stating significant pathogen concentrations in urban highway runoff originate from the USA, measuring methods and further information on the test conditions (resp. the related sewage system) were not denoted. It is therefore likely, that high concentrations of fecal coliform bacteria in highway runoff result from combined rainwater and sanitary sewage systems.

3.1.3 Ingredients of highway runoff water

The literature available on pollution of precipitation runoff is heterogeneous, since different parameters are observed in various measuring programs and even analysis and evaluation of results are different [DWA and DBU, 2010]. Also, the idiosyncrasies of different sites (f. e. location, maintenance activities or DTV) must be regarded.

[77] *Escherichia coli*

[78] pathogens may result from bird dung, agriculture or losses from animal transportation [WINKLER, 2005]

WINKLER (2005) states a significant difference between highway runoff from urban or rural areas.

In anticipation of the finding of an evaluation method for decentralized stormwater treatment in separate sewage systems that will be looked at in Chapter 5, the German association for water management, waste and wastewater (DWA) determined minimum and maximum values, confidence intervals[79] and centroid values for some relevant parameters (the sum parameters TSS, COD, PAH, MOTH[80] and for heavy metals the key components copper and zinc), each for precipitation runoff from roof areas, traffic areas[81] and mixed use areas. The given centroid values and confidence intervals were not determination by statistical or mathematical criterions, but by professional assessment of each measuring program taken as a basis. [DWA and DBU, 2010] TSS, COD and MOTH are given in [mg/L]:

	Min. value	**Max. value**	**Confidence interval**	**Centroid value**
TSS	20 mg/L	1,925 mg/L	60 mg/L – 400 mg/L	200 mg/L
COD*	< 1 mg/L	300 mg/L	30 mg/L – 150 mg/L	100 mg/L
MOTH**	< 0.5 mg/L	351 mg/L	1 mg/L – 5 mg/L	1.0 mg/L

* Since COD is not considered to be a decisive substance in runoff water from traffic areas, it was neglected in the subsequent laboratory and in-situ analysis for road runoff treatment facilities. The choice of this parameter was more due to the runoff of other derivation. [DWA and DBU, 2010]

** Analytic methods for MOTH were undergoing several changes over the past few years. This complicates the comparison of measured values. Data on MOTH loads and concentrations should not be assessed without regards to the used analytic methods. [DWA and DBU, 2010]

Tab. 7: Advent of pollutants in runoff water from traffic areas [DWA and DBU, 2010]
Sum parameters total suspended solids (TSS), chemical oxygen demand (COD) and mineral oil-type hydrocarbons (MOTH)

79 range of rather reliable values

80 mineral oil-type hydrocarbons

81 traffic areas are not specified

Copper, zinc and PAH are given in [µg/L]:

	Min. value	Max. value	Confidence interval	Centroid value
Cu	20 µg/L	> 500 µg/L	50 µg/L – 300 µg/L	80 µg/L
Zn	50 µg/L	41,000 µg/L	200 µg/L – 600 µg/L	440 µg/L
PAH	0.6 µg/L	84 µg/L	1.5 µg/L – 7.0 µg/L	2.5 µg/L

Tab. 8: Advent of pollutants in runoff water from traffic areas [DWA and DBU, 2010] Parameters copper (Cu), zinc (Zn) and sum parameter polycyclic aromatic hydrocarbons (PAH)

Building on the results of a six-month pre-study in 2005 and 2006, from June 2006 to July 2007 a research project on "material deposition in soils at the roadside" [KOCHER and BEER, 2007] was conducted on three federal highways (A 4, A 555 and A 61) and the deposition of pollutants in the soil and in the highway runoff were determined as exemplary values for the pollution of soil and groundwater by dense traffic. To determine the atmospheric preload some background measuring stations (measuring especially dust deposit) were installed at a range of 100 meters from the highways. The focus of this study was on the measuring of dust deposit near the ground and near the roadway, runoff water samples were taken[82] and examined from every measuring point to compare results from dust deposit measures. The location of the measuring points were carefully chosen, regarding the general wind direction, the windward or leeward side of the highways and a comparable evenness of traffic flow. At all measuring points the daily traffic volume exceeded 65,000 motor vehicles per 24 hours and the amount of heavy traffic reached from 5,4 % to 19,8 %.

The measuring program focused mainly on the inorganic compounds like salts and metals. An investigation on organic material groups occurring in road runoff (such as PAH) was not made due to the high expenses it requires. Observed were the following substances: calcium (Ca), sodium (Na), chlorine (Cl), iron (Fe), cadmium

[82] samples from runoff percolating over the embankments, no centralized collection device

(Cd), cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb), vanadium (V) and zinc (Zn). Annual patterns[83] of pollutant ingresses in highway runoff were discovered for some substances like cadmium, zinc and iron and especially for compounds of de-icing salts like calcium, sodium and chlorine. Applicable reference values were the precautious concentration values of percolating water given by the German soil protection ordinance (as seen in table 9).

Inorganic compounds*	Test value [µg/L]
Cadmium (Cd)	5
Chromium (Cr) [total]	50
Cobalt (Co)	50
Copper (Cu)	50
Lead (Pb)	25
Molybdenum (Mo)	50
Nickel (Ni)	50
Zinc (Zn)	500
*shows only values for the relevant parameters observed by KOCHER and BEER (2007)	

Tab. 9: Test values on concentrations of inorganic compounds by the German soil protection ordinance [BBODSCHV, 1999]

Some of the parameters could not be measured properly, since the concentrations were below the limit of determination. Table 10 compares the concentrations of some substances that were mostly above the limit of determination during the pre-study 2005/2006 and the concentrations of those substances measured in 2006/2007.

[83] Jahresgänge

	Conductivity [µS/cm]	Ca [mg/L]	Cd [µg/L]	Fe [mg/L]	Na [mg/L]	Zn [mg/L]	pH-value
Median 05/06	330	18.9	0.10	0.05	41	0.101	6.76
Median 06/07	109	9.98	0.05	0.05	9.3	0.068	7.26
Average 05/06	3482	49.6	0.23	0.29	564	0.245	6.83
Average 06/07	334	16.51	0.16	0.83	43.3	0.445	7.24
Standard deviation 05/06	6110	84.1	0.32	1.12	1110	0.501	0.58
Standard deviation 06/07	701	21.47	0.27	2.38	72.9	1.320	0.47

Tab. 10: Comparison of matter concentrations, pH-Values and (electric) conductivity of road runoff from 2005/2006 and 2006/2007 (all samples) [KOCHER and BEER, 2007]

Except for zinc, the measured values are lower in 2006/2007 than in 2005/2006. According to KOCHER and BEER (2007), the high zinc concentrations in 2006/2007 are likely to be slightly distorted by the new built galvanized safety fence on one of the observed highways. The pH-values measured in 2006/2007 are in normal region, rather alkaline, as expected of runoff from concrete or pavement. As explained in the report, the slightly lower pH-values measured in 2005/2006 are because the samples were stored for too long before being examined, which was optimized before the measuring program of 2006/2007. From 2008 to 2009 the research project on “material deposition in soils at the roadside” was continued and the results exhibited minor aberrances in metal concentrations, especially lead and cadmium, which tended to be slightly lower[84] [KOCHER and BEER, 2009].

A similar research project by DIERKES (no year) in one of the most dense and industrialized urban agglomeration areas in Germany[85] on percolation water and soil samples from highways close to Essen. The main objective of this study was to determine the impact of highway runoff water percolating through greened embankments on groundwater. For this purpose, lysimeters filled with soil-monoliths were buried into the embankments of five highly frequented highways (A 2, A 3, A 31, A 42 and B 224[86]), while in the laboratory parallel research was conducted on highway runoff that was collected before making its way through the soil passage to determine the retention and purification performance of soil from different highway embankments. In addition to that, the soil was analyzed in the depth of 0 – 5, 5 – 10 and 10 – 30 cm. The duration of the project was three years; samples were taken weekly. Several heavy metals, dissolved or particle-bound, were analyzed. The runoff from highway A 2, in contrast to the other four, is not infiltrated over the embankments, but collected in a sewer. Highway A 2 was observed to study the difference between runoff and splashwater infiltration. On this account, highway A 2 is not listed in table 11. Samples from highway A 3 were not evaluable. Highway A 43 was an additional measuring point; samples were taken from a detention pond. Table lmn shows the concentration of the most detected heavy metals. By filtering the samples at 0.45 µm dissolved heavy metals were separated from particle-bound heavy metals. This analysis revealed that except from lead, which was found with approx. 10 % dissolved matter, the tested heavy metals showed a rather high mobility and in order to that are more hazardous to groundwater.

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[84] full data were not available

[85] the “Ruhrpott”

[86] B 224 actually is no highway, but a federal road. Due to its DTV of 52,000 motor vehicles / 24h it was treated as an official highway. The federal highway A 2 showed the highest DTV with 107,600 motor vehicles / 24 h.

	Total heavy metals				Dissolved heavy metals			
	Zn [mg/L]	Cu [µg/L]	Pb [µg/L]	Cd [µg/L]	Zn [mg/L]	Cu [µg/L]	Pb [µg/L]	Cd [µg/L]
A 43	0.8 – 3.0	80 – 130	10 – 20	0.8 – 3.6	0.3 – 1.3	17 – 56	n. d. – 10	n. d. – 0.7
A 31	–	40 – 150	4 – 60	0.5 – 1.0	–	20 – 80	n. d.	n. d. – 0.6
A 42	0.7 – 41.0	60 – 70	10 – 40	1.7 – 3.3	0.2 – 23.1	30 – 60	n. d.	n. d. – 2.4
B 224	0.2 – 0.8	60 – 160	n. d. – 4	0.7 – 7.6	0.1 – 0.6	20 – 50	n. d.	n. d. – 1.8
n. d. = not detectable								

Tab. 11: Average heavy metal concentrations in runoff samples from four federal highways [DIERKES, no year]

Amongst pH-value, grain size distribution, total carbonate and the heavy metals cadmium, copper, lead and zinc, concentrations of mineral oil-type hydrocarbons (MOTH[87]) and polycyclic aromatic compounds (PAH) were determined in the soil samples to examine the accumulation and degradation processes of pollutants in embankment soils.

The analysis displayed that heavy metal concentrations go down with distance[88] and depth[89]. The same can be said for PAH, which are filtered to a great extend by the upper ten centimeters of the soil due to their affinity to fine particles. It was also revealed that PAH concentrations increased with traffic density. The comparison with values from reference samples away from the roadside (to determine the atmospheric preload) showed that all PAH concentrations[90] are significantly higher in highway embankment soils. Especially some observed types of PAH like

[87] abbreviation adapted from DIERKES (no year)

[88] highest concentrations were found up to two meters from the highway

[89] The passage of the upper five centimeters of vegetal soil made heavy metal concentrations decrease up to 25 %, except for cadmium.

[90] no precise data given

benzo(a)pyrene, pyrene, benzo(a)anthracene, benzo(b)+(k)-fluoranthene and ideno(1,2,3-cd)pyrene displayed increased values. Flouranthene and benzo(g,h,i)perylene showed highly divergent values.

Mineral oil-type hydrocarbons mostly originate from car leakages and are not transported by air, which causes the concentrations to rapidly decrease with distance. Since MOTH are to a great extend biodegradable the concentration values also go down with the soil passage, especially in the warm month of spring and summer.

Table 12 lists the concentrations of cadmium, copper, lead, zinc, PAH and MOTH in embankment soils dependent on depth and distance.

Highway	Depth	Dis-tance	Pb	Zn	Cu	Cd	PAH	MOTH
	[cm]	[m]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
BAB 2	0-5	0,5	239	527	413	3,9	6,7	150
	5-10	0,5	202	361	78	3,5	11,3	110
	10-30	0,5	34	99	31	2,7	5,3	57
	0-5	0,3	213	398	121	3,4	16,6	190
	0-5	2	220	336	95	3,0	9,4	74
	0,5	5	141	231	42	2,0	9,4	62
	0-5	10	65	155	27	1,8	2,1	36
BAB 3	0-5	2	81	174	25	2,0	5,3	200
	5-10	2	69	141	20	1,9	7,0	73
	10-30	2	67	114	11	1,1	5,0	23
BAB 31	0-5	0,75	276	759	268	4,3	< 2,1	28
	5-10	0,75	130	303	69	2,6	< 2,1	23
	10-30	0,75	54	112	24	2,5	< 1,6	12
BAB 42	0-5	2	290	1580	167	5,6	23,0	510
	5-10	2	348	1630	155	8,5	16,9	220
	10-30	2	27	138	23	3,1	< 1,6	60
B 224	0-5	0,75	71	187	40	2,2	2,5	160
	5-10	0,75	53	120	42	2,5	< 1,9	25
	10-30	0,75	18	69	24	-	< 1,7	21

Tab. 12: Concentrations of heavy metals (total), PAH and MOTH in [mg/kg] at different depth and distance on five federal highways [DIERKES, no year]

3.1.4 Priority hazardous substances

In 2001 the European water framework directive (2000/60/EC) was revised and a list of priority substances, which are known or estimated to be hazardous to water resources, were added as tenth attachment. This annex No. X. classifies the priority substances into the following three categories:

- priority substances
- priority hazardous substances
- priority hazardous substances to examine[91]

Not all of those substances are "new" to the water framework directive. The list also contains a large number of "old" substances that were classified as water-hazardous in earlier times, f. e. heavy metals like lead or cadmium. Also, many of those substances are pesticides or preservatives that have been prohibited in Germany and other Member States for al long time and are still found in water bodies and sediments. Other substances predominantly emerge from industrial processes.

There are several priority and priority hazardous substances that originate from vehicle installations, agents, drip losses or exhaust fumes (combustion or incomplete combustion). Priority substances related to traffic are from the substance groups heavy metals, phenolics, plasticilizers, PAH or VOC[92]. Furthermore, atmospheric preloads can contain priority hazardous substances that settle on road surfaces. Table 13 shows priority hazardous that can potentially be found in highway runoff stated by KOCHER (2011) and possible sources.

[91] The European commission had yet to categorize these substances into priority substances or priority hazardous substances. The Member States were requested to agree on quality standards until 2002 or determine their own national quality standards for these substances.

[92] volatile organic compounds

Substance	Category	Possible Sources
Benzene	ps	exhaust fumes atmospheric preload
Bis(2-ethylhexyl)phthalates (DEHP)	phse	atmospheric preload vehicle installations (used as plasticilizer in synthetic products)
Cadmium and cadmium compounds	phs	abrasion of tires exhaust fumes resp. carbon black (soot) corrosion products
Lead and lead compounds	phse	abrasion of tires exhaust fumes resp. carbon black (soot)
Nickel and nickel compounds	ps	abrasion of road surfaces abrasion of brake lining drip losses (possible fuel compound)
Nonylphenoles	phs	abrasion of tires (used as vulcanization resin) exhaust fumes atmospheric preload
Octylphenoles	phs	abrasion of tires (used as vulcanization resin) exhaust fumes atmospheric preload
Benzo(a)pyrene **Benzo(b)+(k)-fluoranthene** **Benzo(g,h,i)perylene** **Ideno(1,2,3-cd)pyrene** **(PAH)**	phs	exhaust fumes atmospheric preload drip losses (possible fuel compound) abrasion of tires
Anthracene **Paranaphthaline** **(PAH)**	phse	exhaust fumes atmospheric preload drip losses (possible fuel compound) abrasion of tires
Fluoroanthene **(PAH)**	ps	exhaust fumes atmospheric preload drip losses (possible fuel compound) abrasion of tires

PAH (sum parameter)	phs	exhaust fumes atmospheric preload drip losses (possible fuel compound) abrasion of tires
Trichlorbenzenes	phse	atmospheric preload (was widely used as dissolvent or herbicide, usage restrictions in most Member States*)
ps = priority substance **phs = priority hazardous substance** **phse = priority hazardous substance to examine**		

Tab. 13: Categorization of priority substances and priority hazardous substances of the EU water framework directive that can be found in highway runoff [KOCHER, 2011] and possible sources [WINKLER, 2005; UBA and URL; 02/06/2012]
* Supplement: Information taken from annex 4 from the Hessian measurement program for the implementation of the European Water Framework Directive [HMUELV, URL; 12/28/2011]

The priority hazardous substances are toxic[93] and highly persistent compounds. Most of them are organic compounds. Other potentially traffic relevant organic pollutants that are not covered by the European water framework directive are f. e. bisphenole A, benzothiazole and benzothiazole compounds (2-methyl-thiobenzothiazole, 2-methyl-benzothiazole, mercaptobenzothiazole) or polychlorinated biphenyls (PCB). The properties of organic pollutants in soil or water and their mobility strongly depend on the molecular shape and mass, the polarity and the reactivity to water. [Kocher, 2011] The same can be said for heavy metals. Additionally the pH-value is crucial to heavy metal mobility, since the solubility increases under acidic conditions.

Most priority hazardous substances are affiliable to the fine fraction of suspended solids, which leads to an accumulation of substances in the soil or the sediments of receiving waters if highway runoff is discharged untreated [Winkler, 2005]. By filtering and sedimentation, the major part of priority hazardous substance load can be eliminated.

[93] to human health or to fish and aquatic organisms

The partitioning of particle-associated pollutants (heavy metals and especially PAH) in relation to different particle sizes were analyzed in a study on “road runoff pollution by polycyclic aromatic hydrocarbons and its contribution to river sediments” by KREIN and SCHORER (2000). The objective was to determine the pollutant distribution to different materials (organic and inorganic suspended solids) and particle size fractions, since dissimilar hydraulic conditions lead to specific mobilization, transport and remobilization of different particle sizes. Also, small organic particles are consumed by benthic organisms rather than inorganic solids. Therefore the pollutants affiliated to organic particles are more likely to access the food chain. Furthermore, pollutants will be mobilized by decomposition of the organic matter they are attached to. Thus, this investigations approach was different from “traditional analysis of particle size distribution in soil or sediment samples”, which mostly involves the removal of the organic material and thus leads to adulteration of measured data. KREIN and SCHORER apportioned the particles and attached pollutants “under conditions as undisturbed as possible”, where pollutants like PAH often associate with natural organic particles as well as inorganic particles. Also, processes like natural coagulation and aggregation were taken account of. Samples were taken from road dust, road runoff and river sediments in a study area in the Hunsrück (Germany) and tested for selected heavy metals[94] and PAH[95]. Since no daily traffic volume was stated in the report, the measured concentration values should not be considered in comparison with the studies of KOCHER and BEER (2007) or DIERKES (no year). Yet, the study provides important findings about the connection between suspended solid fractions and pollutants.

[94] Pb, Cu, Zn, Fe, Mn

[95] some of the PAH listed by the United States Environmental Protection Agency (EPA): Fluorene, anthracene, phenanthrene, fluoranthene, indeno(c,d)pyrene, dibenz(a,h)anthracene, benzo(g,h,i)perylene

While the heavy metal concentrations showed the frequently observed “inverse relationship” to the average particle size[96] the results were different for PAH, as seen in table 14.

n = 8		Particle size in µm					
Substance	**Unit**	**< 2**	**2 – 6.3**	**6.3 – 12.5**	**12.5 – 20**	**20 – 63**	**63 – 200**
Fluorene	µg/kg	21 (1.1)	47 (2.1)	51 (2.5)	60 (2.6)	32 (1.5)	74 (3.3)
Anthracene	µg/kg	24 (1.2)	61 (3.1)	65 (3.3)	72 (3.2)	64 (3.3)	147 (7.4)
Phenanthrene	µg/kg	183 (7.7)	733 (37.5)	763 (37.7)	766 (34.3)	580 (23.2)	1022 (52.1)
Fluoranthene	µg/kg	350 (16)	1622 (83)	1554 (67.6)	1155 (48.7)	1078 (39.9)	1958 (93.3)
Indeno(c,d)pyrene	µg/kg	86 (3.8)	402 (22.2)	271 (12.6)	76 (3.2)	127 (5.4)	146 (6.8)
Dibenz(a,h)anthracene	µg/kg	20 (0.9)	83 (3.8)	66 (3.5)	11 (0.39)	34 (1.8)	41 (2.1)
Benzo(g,h,i)perylene	µg/kg	139 (6.9)	710 (31.9)	541 (27.8)	217 (9.8)	287 (12.3)	281 (13.7)
TOC	%	14 (0.1)	22 (0.3)	25 (0.2)	27 (0.3)	19 (0.1)	30 (0.2)

Tab. 14: Average concentrations (and standard deviations) of selected PAH and the total organic carbon content in different particle-size fractions of eight road runoff material samples (n = 8) taken during a precipitation event on September 12th in 1997. [KREIN and SCHORER, 2000]

The finest particle size < 2 µm (clay fraction) constantly showed the lowest PAH concentrations in general. The particle sizes 2 – 6.3 µm (finer middle silt[97] fraction) and 6.3 – 12.5 µm (fine middle silt fraction) held the highest concentrations of indeno(c,d)pyrene, dibenz(a,h)anthracene and benzo(g,h,i)perylene, three PAH with five and six benzene rings (also seen in fig. 9), while smaller PAH molecules with three benzene rings like fluorene, anthracene and phenanthrene exhibited highest concentrations in the particle fraction from 63 µm to 200 µm (fine sand fraction, also

[96] The smaller the average particle size, the higher the concentrations

[97] Schluff

seen in fig. 10). KREIN and SCHORER also proved that smaller PAH molecules accumulate faster than larger molecules.

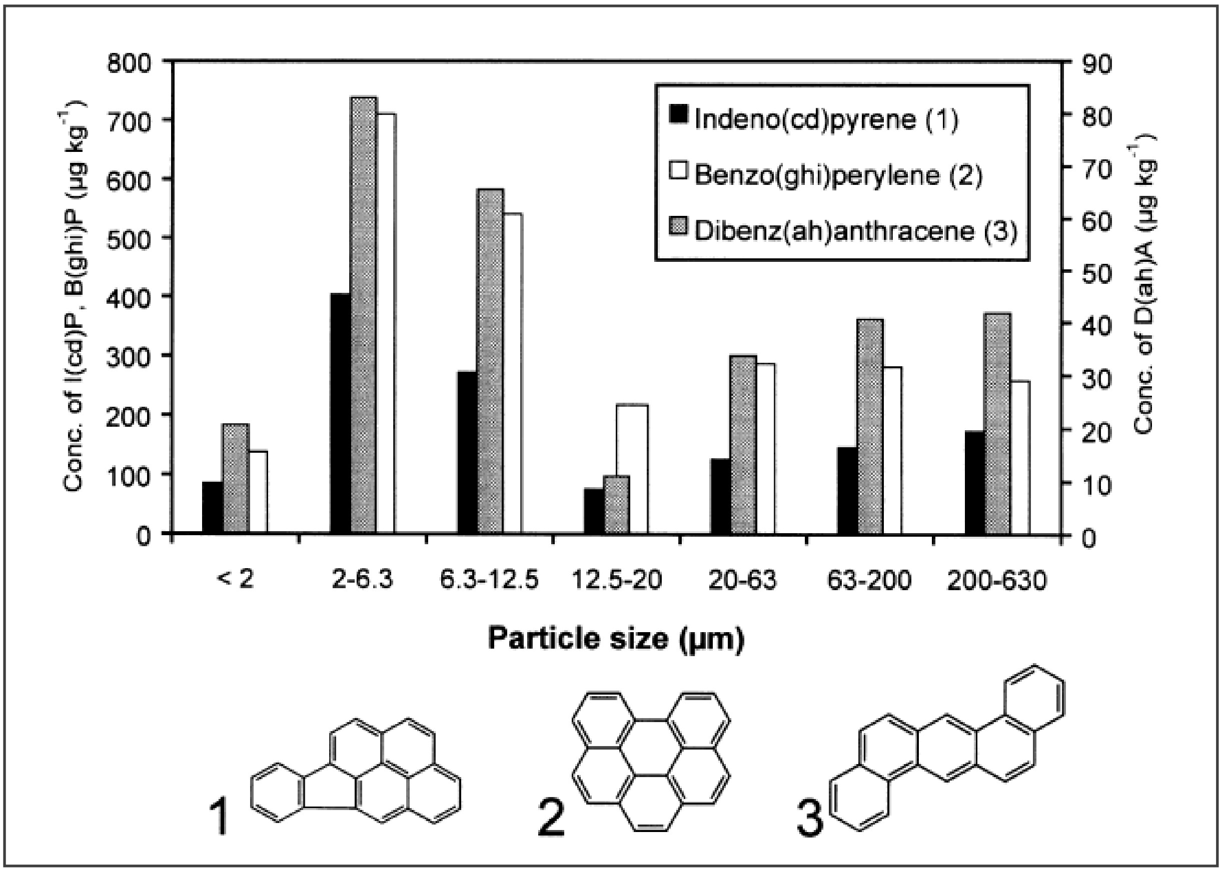

Fig. 9: Concentration of five- and six-ring molecule PAH in different grain sizes [KREIN and SCHORER, 2000]

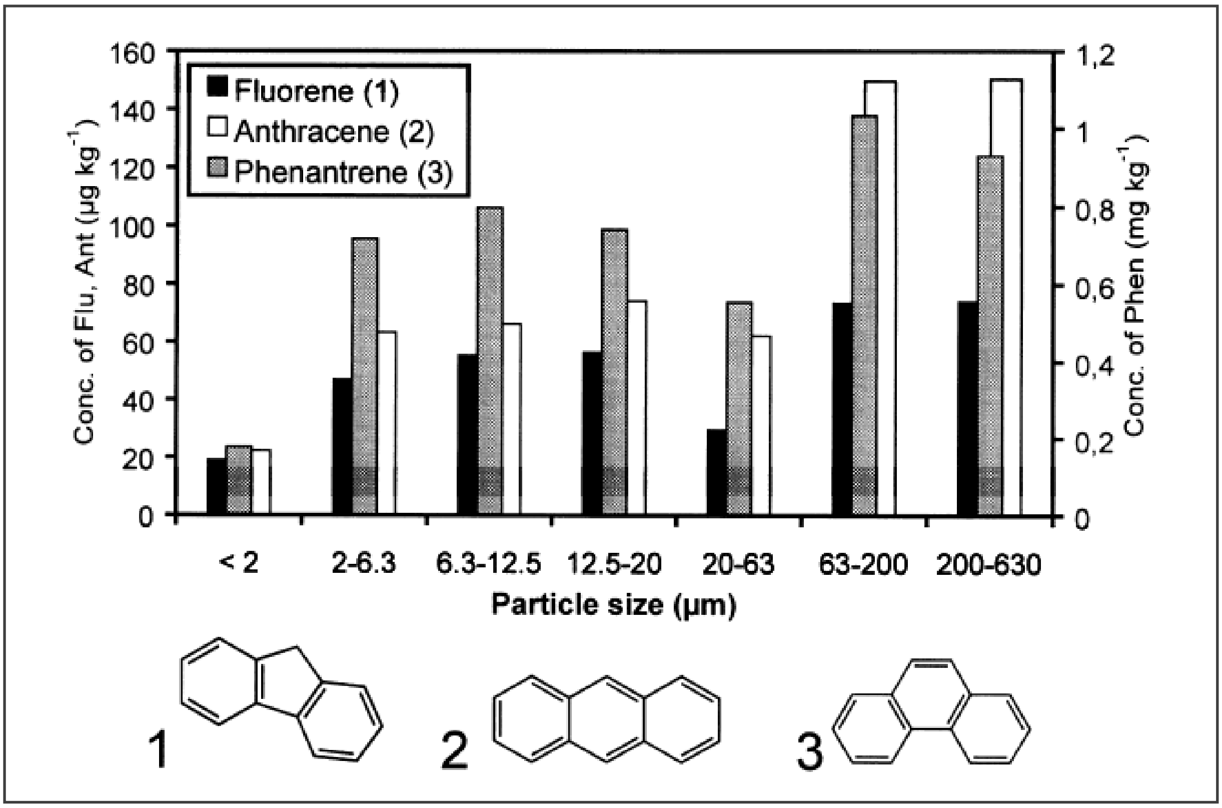

Fig. 10: Concentration of three-ring molecule PAH in different grain sizes [KREIN and SCHORER, 2000]

On national level there exist different limit values and quality aims for the effluent concentration[98] (Wastewater Ordinance) or the concentration in water bodies (German quality aim) of priority hazardous substances, as seen in table 15. In comparison to that table 16 shows maximum permitted concentrations (2008/105/EC Directive for Environmental Quality Standards in Water Policy) given by the European Commission and annual average values from monthly analysis. [UBA, URL; 02/06/2012] and [HMUELV, URL; 01/10/2012, annex 2-9]

[98] maximum permitted concentration for discharging wastewater into receiving waters

Substance	German quality aim (objective value)	German Wastewater Ordinance (max. effluent concentration)
Benzene	10 µg/L	Different sector-specific limit values from 0.05 mg/L (industry producing hydrocarbons) to 10 mg/L (graphical and printing produce)
Bis(2-ethylhexyl)phthalates (DEHP)	0.8 µg/L (Rhine)	No specification on DEPH (sum parameters for similar organic substances apply)
Cadmium	1.2 mg/kg VSS 0.07 µg/L	Different sector-specific limit values from 0.01 mg/L to 1.8 mg/L
Lead	100 mg/kg VSS 3.4 µg/L	0.5 mg/L
Nickel	120 mg/kg VSS 4.4 µg/L	0.5 mg/L
Nonylphenole	No data (European quality aim: 0.3 µg/L, max. concentration 2.0 µg/L)	No data
Octylphenole	No specification, suggested objective value: 0.12 µg/L (European quality aim: 0.06 µg/L)	No data
PAH	0,01 µg/L* 1.0 µg/L** 0.025 µg/L***	0.015 g/t (for hard coal industry)
1,2,4-Trichlorbenzene	4 µg/L	0.5 mg/L – 10 mg/L (depending on production process)

* as sum parameter for anthracene, benzo(a)pyrene
** as sum parameter for paranaphtaline
*** as sum parameter for fluoranthene, benzo(b, k)-fluoranthene, benzo(g,h,i)perylene, ideno(1,2,3-cd)pyrene

Tab. 15: Environmental quality aims and limit values for selected (relevant to highway runoff) priority hazardous substances [UBA, URL; 02/06/2012]

Substance	Max. permitted concentrations 2008/105/EC Environmental quality standard	Annual average concentrations Environmental quality standard
Benzene	50 µg/L	10 µg/L
Bis(2-ethylhexyl)phthalates (DEHP)	No specification	1.3 µg/L
Cadmium and cadmium compounds	< 0.45 – 1.5 µg/L (depending on hardness of water)	< 0.08 – 0.25 µg/L (depending on hardness of water)
Lead and lead compounds	No specification	7.2 µg/L
Nickel and nickel compounds	No specification	20 µg/L
Nonylphenole	2.0 µg/L	0.3 µg/L
Octylphenole	No specification	0.1 µg/L
PAH	0.4 µg/L (anthracene) 1.0 µg/L (fluoaranthene) no specification for paranaphtaline 0.1 µg/L (benzo(a)pyrene) no specification on benzo(b, k)-fluoranthene, benzo(g,h,i)perylene, ideno(1,2,3-cd)pyrene	0.1 µg/L (anthracene) 0.1 µg/L (fluoranthene) 2.4 µg/L (paranaphtaline) 0.05 µg/L (benzo(a)pyrene) 0.03 µg/L (benzo(b, k)-fluoranthene) 0.002 µg/L (benzo(g,h,i)perylene and ideno(1,2,3-cd)pyrene)
Trichlorbenzenes	No specification	0.4 µg/L

Tab. 16: Limit values given by the European Directive for Environmental Quality Standards in Water Policy and annual average values for selected (relevant to highway runoff) priority hazardous substances [HMUELV, URL; 01/10/2012, annex 2-9]

3.2 State of the art

Highway runoff treatment can be distinguished in centralized and decentralized treatment. In centralized treatment the precipitation runoff from different areas is collected and mingled in the stormwater channel (assuming a separation system) and supplied to a central runoff treatment facility. Possible facility types are f. e. stormwater sedimentation tanks, retention soil filters, sedimentation tanks or RiStWag-Separators [PFEFFERMANN, 2011]. Decentralized treatment deals with runoff from smaller areas, since the runoff is treated immediately at its source. The most important treatment method is the extensive percolation through roadside soils the resp. the embankments of highways. Other possible treatment systems are f. e. percolation troughs, infiltration trenches or trench-trough percolation facilities.

Pollutants can be removed from the runoff water by various processes that are more or less intensively used in treatment facilities. Light liquids can be skimmed off the water surface due to their buoyancy, which is accomplished by a light liquid separator. Mostly, light liquids are also biodegradable. Particulate matter is mostly removed from the water by sedimentation (settlement) or filtration, artificial (f. e. application of filter fabrics, membranes) or natural (f. e. retention soil filter, top soil passage). Also, biodegradation is a possible removal process for suspended solids. Dissolved substances can be removed by processes that eliminate the pollutant instantly (f. e. sedimentation, biodegradation, bioaccumulation, photolysis) or transform dissolved pollutants into complexes (f. e. chemical precipitation, flocculation).

In line with the thesis this section basically draws upon [PFEFFERMANN, 2011] this term paper provides a brief overview [footer: Further information about the systems and costs as well as calculations on design and dimensioning of stormwater treatment facilities can be looked up in PFEFFERMANN, 2011] of current stormwater treatment methods and facilities arranged by the categories “mechanical treatment”, “chemical and physical treatment”, “filtration” and “nature-orientated treatment”. “Special treatment systems” for highly polluted runoff will be issued briefly in addition.

Table 17 shows current stormwater treatment methods allocated to the particular categories that will be discussed in this section.

Mechanical treatment	**Chemical and physical treatment**	**Filtration**	**Nature-orientated treatment**
Rakes and Screens	Chemical precipitation and flocculation	Sand filter	Extensive and trough percolation
Sedimentation	Adsorption and desorption	Pile fabric and micro filter	Retention soil filter
Grit chamber		Membrane filtration	
Sedimentation tank		Technical filtration	
Vortex-Separator			
Lamella separator			
RiStWag- Separator			

Tab. 17: Treatment methods allocated to different categories (treatment approaches) [modified according to PFEFFERMANN, 2011]

3.2.1 Mechanical treatment

Since road runoff often contains leafs, logs, litter and various coarse-grained materials like road surface or vehicle abrasion, the first step in treatment facilities is the sieving by *rakes* and *screens*. This does not only extract a high amount of undesirable materials, but also protects the downstream facility components from clogging.

Rakes are distinguished by their width (space between bars) in coarse rakes (40 – 100 mm) and fine rakes (5 – 30 mm). Straight steel bars, arranged in a gradient of 1:2 to 1:3, and mechanical bar screens to prevent blockages are usually applied. Screens are categorized by their mesh size in macro screens (0.3 mm) and micro screens (< 0.1 mm). Besides the “sieving-effect” micro-screening is almost comparable to filtration. Coarse rakes only remove the grittiest and most coarse-grained solids, while downstream micro-screening, dependent on the solid concentration, can achieve retention performances from 60 to 80 % TSS, which is due to a layer of solids that evolves on the screen surface and has a further filtration effect [SIEKER, URL; 02/19/2012].

Another effective way to remove solids is by *sedimentation*. Sedimentation describes a process of solids that settle out of the fluid they were suspended in under the influence of a force field, f. e. gravity, centrifugal force or electromagnetism, in wastewater treatment it is gravity. Suspended solids sink down and settle on the ground “at a constant velocity as soon as lift and drag force are in equilibrium with gravity” [PFEFFERMANN, 2011]. The grain size, shape and density of the suspended solids determine their settling velocity. This can be theoretically calculated, which is a rather complex process, since some particles change their physical properties in the process of settling. Also, “fluctuating water temperatures” influence the settling process. The mostly used calculatory approach is the “settling process in laminar flow” [PFEFFERMANN, 2011].

Grit chambers, usually applied behind the screening facility, apply this removal process for solids with a grain diameter of 0.1 – 0.2 mm (mostly sand). The flow velocity is reduced to the amount needed for those particles to sink down to an area without flow (the sand collection chamber). The facility types long, round and deep grit chambers can be distinguished. They often are combined with separators for light liquid resp. light density materials (“grease basins”) and baffles (as seen in figure 11). Although the space requirement is rather low, it must be examined if the surface is large enough for the aspired particle removal, since turbulent flows, which can cause temporary flotation of already settled particles, cannot be excluded. [PFEFFERMANN, 2011]

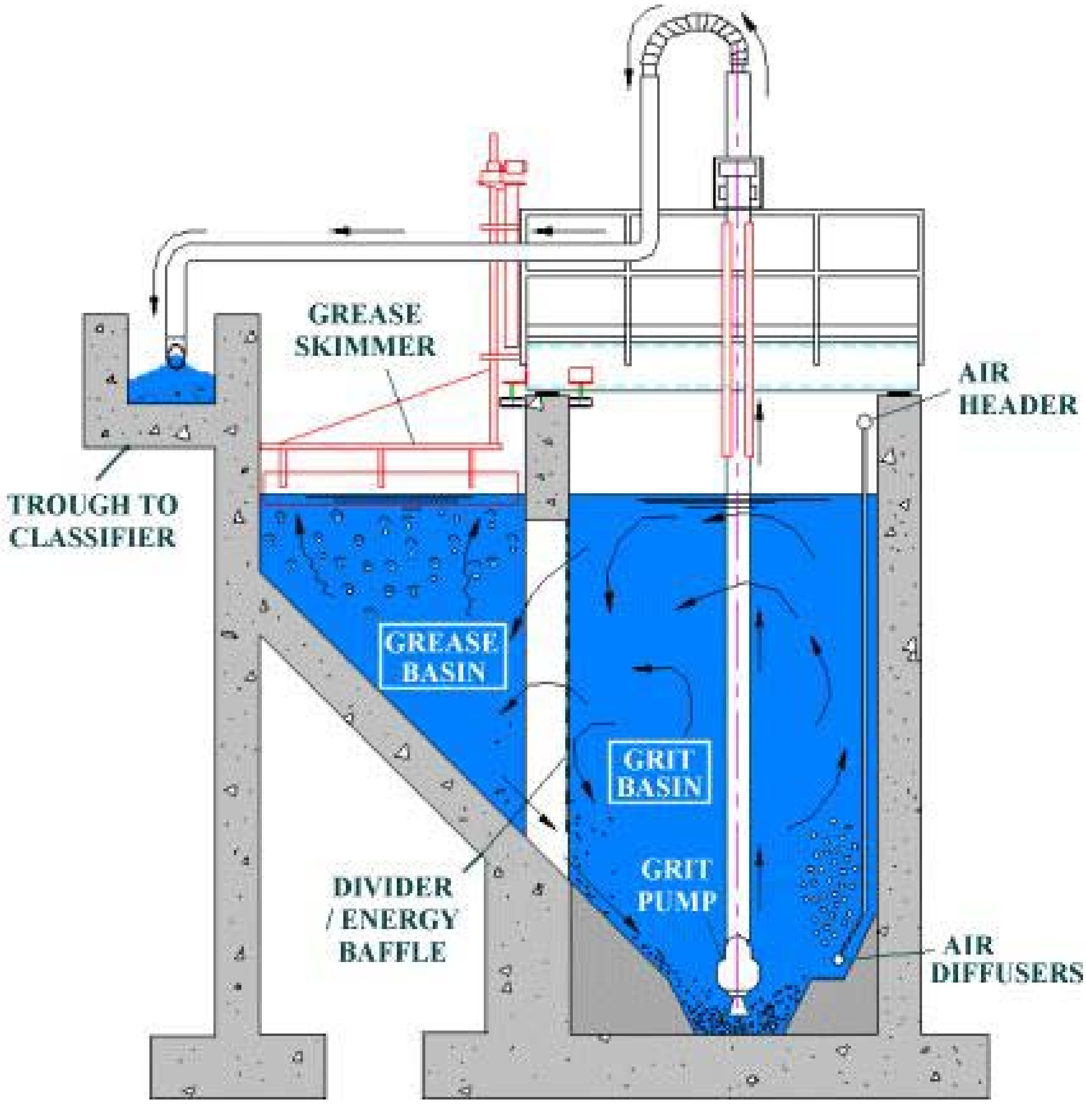

Fig. 11: Combined grit chamber and grease basin [SEWAGETREATMENT.US, URL; 02/25/2012]

Unlike grit chambers, which can be applied in the combined as well as separate sewage system, *stormwater sedimentation tanks* are used only in the separate system. The reduction of flow velocity that is required for the settling process of suspended solids (flow rate about 10 m/h) is achieved by an expanded flow cross section. The pollutants that are removable by this method are suspended solids as well as hazardous substances that are associated with particles. The sedimentation does not apply for dissolved pollutants. Stormwater sedimentation tanks can be distinguished in facilities with and without permanent storage. [PFEFFERMANN, 2011]

The design *stormwater sedimentation tank without permanent storage* correlates with stormwater storage tanks in the combined sewage system. They are not constantly flooded with water, but perform as buffer volumes for heavy rainfall, designed as stormwater tanks with regular or throttled overflow or upstream structures with overflow. Tanks without permanent storage are emptied after storm events. Thus, sediments are removed more often than in stormwater sedimentation tanks with permanent storage and they require a temporarily used connection to the wastewater sewer system. [PFEFFERMANN, 2011]

Stormwater sedimentation tanks with permanent storage are constantly flooded with runoff water, with the advantage that even small amounts of runoff can be effectively treated by sedimentation. Thus, sediments are only removed, when the storage volume is not sufficient anymore. According to PFEFFERMANN (2011) an extra volume for sludge storage, desirably a storage depth of at least 2 m, must be provided. There are open and closed stormwater sedimentation tanks with permanent storage. In closed systems ventilation openings should be applied to prevent anaerobic processes that might cause a re-dissolution of particle-bound hazardous substances. [PFEFFERMANN, 2011]

Vortex separators also work according to the principle sedimentation. Solids can be separated from stormwater runoff under relatively low head loss, due to different velocities that are caused by the cylindrical shape of the separator and the tangential introduced inflow. The flow rates are low in the middle of the cylinder, while they are high along the inner walls. This difference causes secondary vortices near the walls, which form a zone of small horizontal velocities that facilitate the sedimentation of suspended solids. The settled solids accumulate in the sludge channel and are discharged to the sewer channel by the sludge take-off, which avoids the necessity of cleaning the separator. The outlet for the cleaned water is located between two baffles, which in case of overload are swamped completely and thus “provide the required cross-section for the emergency outlet” [PFEFFERMANN, 2011]. [SIEKER, URL; 02/24/2012]

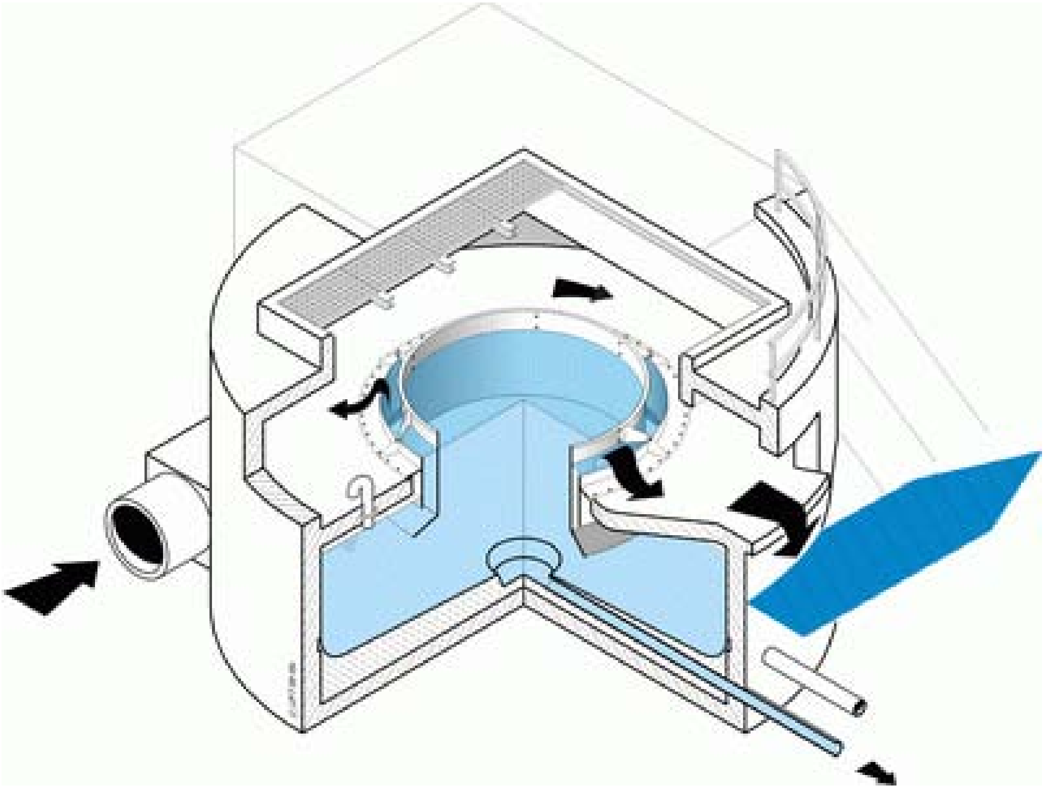

Fig. 12: Vortex separator [UFT, URL 02/25/2012]

Lamella separators improve the efficiency of the sedimentation process by the installation of parallel lamella plates (or honey-combed bundled pipes) made out of stainless steel or polymers, which increase the effective sedimentation area of existing sedimentation tanks. Lamella separators are designed according to the sinking velocity and particle sizes of the suspended solids that should be treated. Hence, “the 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, 2010, quoted by PFEFFERMANN, 2011]. Hydraulic conditions and required sedimentation area and volume must be regarded. A consistent upstream flow is required to obtain a uniform hydraulic pressure on the lamella [RÖLLE and KOLISCH, 2001].

The standard built-up of a lamella separator consists of an inflow chamber, a pumping and flushing sump, an inflow plate, the actual sedimentation chamber, a flushing reservoir and a scum board at the outlet. Runoff runs through the pumping and flushing sump across the inflow plate, which distributes the flow under the lamellas, into the sedimentation chamber. If the tank is empty, the lamellas have a vertical position. When the separator tank is flooded, the lamellas are lifted into their working position with an inclination of 45 degrees. Solids are separated while the water flows through the lamellas towards the outlet. After the storm event the water is drained off the tank into the sewer system. With the dropping water level the lamellas come into a vertical position again, which removes the solids that settled on them. The tank is cleaned by a flush system. [PFEFFERMANN, 2011]

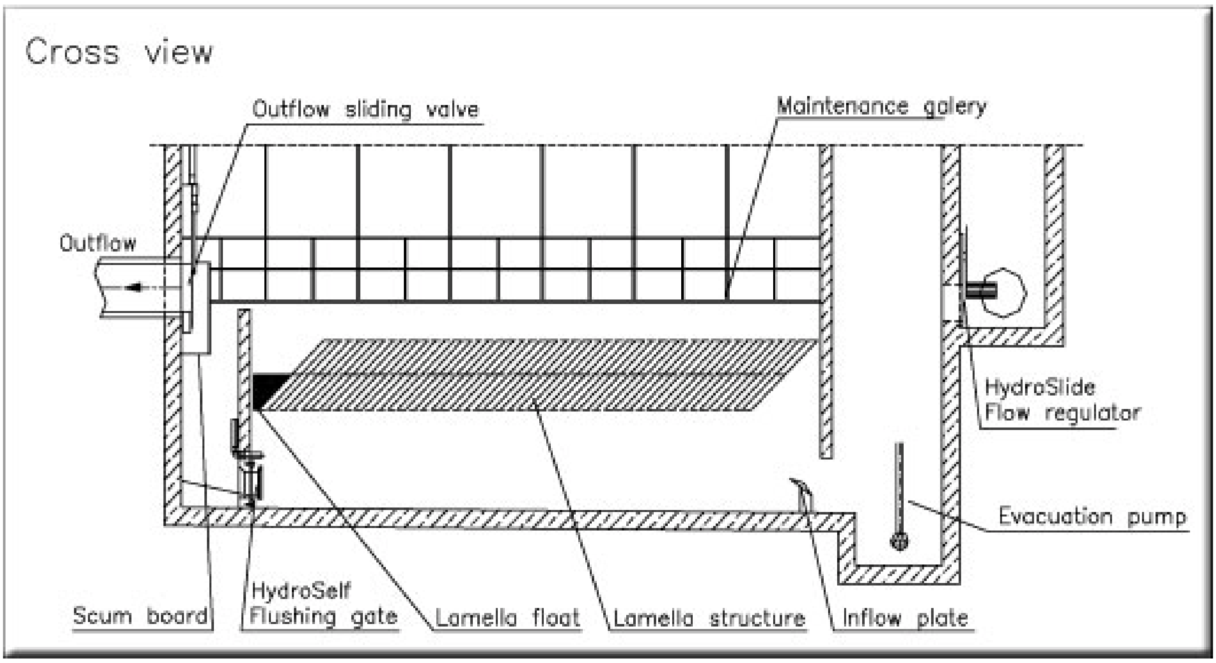

Fig. 13: Cross view of a lamella separator functional diagram (flow from right to left) [STEINHARDT, URL; 02/26/2012]

The *RiStWag-Separator* is used within water protection and abstraction areas, where special requirements on construction and used materials are made by the RiStWag. RiStWag-Separators must not only remove separable solids and attached pollutants from the runoff water, but also retain high amounts of water-hazardous substances in case of an accident. RiStWag-Separators are large facilities with permanent storage [UNITRACC, URL, 02/26/2012]. The sedimentation basin should be three times longer than wide to guarantee a steady flow. There are two different approaches for the designing, which are described in the RiStWag as well as by PFEFFERMANN (2011).

3.2.2 Chemical and physical treatment

Chemical and physical treatment of highway runoff takes advantage of various natural processes, such as chemical precipitation, flocculation and adsorption or desorption, that are able to transform dissolved or finely dispersed substances (organic pollutants, dissolved heavy metals as well as colloids) in a separable and removable form. By addition of active substances or the application of specially coated surfaces those processes are initiated.

To activate *chemical precipitation* a chemical precipitating agent is mixed into the wastewater. With the alteration of the pH-value and the solubility equilibrium of the involved substances this agent reacts with the dissolved pollutant and forms so-called micro-flakes of a mostly difficultly soluble precipitate [ECKHARDT, HERMANN and MEYER, 2010]. The process of chemical precipitation (also called coagulation) mostly merges seamlessly into the process of *flocculation*, if the respective flocculating agent is added. The chemical precipitation, as seen before, creates micro-flakes, which by flocculation are transformed to macro-flakes by destabilization of the molecule structure and charge (the repulsive forces between molecules and particles are abolished). By stirring, macro-flakes agglomerate further and form even bigger units, which are easily filterable or removable by sedimentation or flotation, depending on the chemical composition of the flakes and the applied technology.

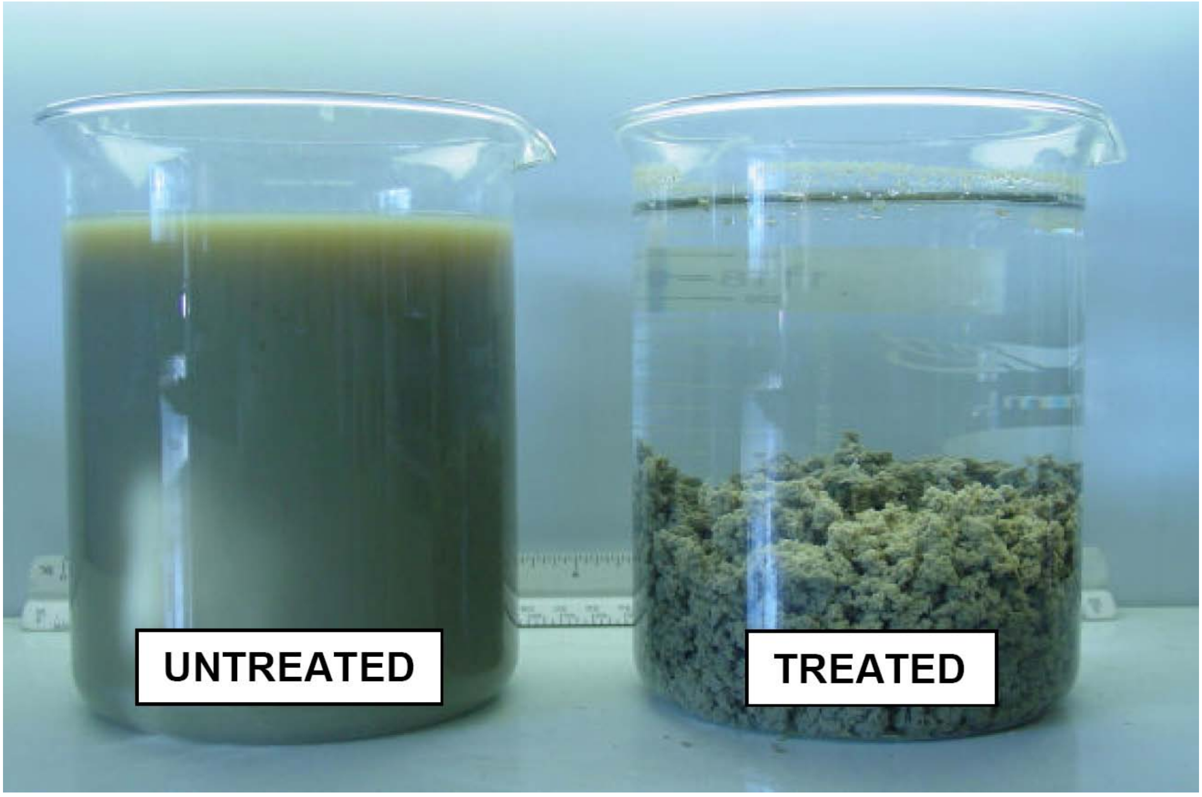

Fig. 14: The chemical process of coagulation shown in a laboratory test. The "treated" jar shows the settled macro-flakes [WECLEANWATER, URL; 02/26/2012]

The dosage of flocculating agents must be finely tuned in order to achieve the desired results. An overdose can lead to the re-stabilization of the suspension, while too low doses will not sufficiently reduce the repulsion potential of the suspended particles. [PFEFFERMANN, 2011]

Adsorption and desorption also are natural processes. Ions or molecules of dissolved pollutants (adsorbate) are attached to the surface of a solid material (adsorbent) on account of natural physical forces [ECKHARDT, HERMANN and MEYER, 2010]. The artificial adsorbents that are used to remove dissolved organic pollutants and heavy metals must show high adsorption capacity and be easily removable from the cleared water. In highway runoff treatment, adsorbent layers of coated filter sand, mostly with zeolite or iron hydroxide, are applied. Since an acidic chemical milieu could lead to iron hydroxide detachments, iron hydroxide adsorbent layers require a pH-value higher than 3. Zeolite adsorbent layers should not be used in winter, since the high content of deicing salts in highway runoff could cause a re-dissolution of adsorbed pollutants. Additionally to the adsorption the coated sand layers show a filtration effect. [PFEFFERMANN, 2011]

3.2.3 Filtration

Filtration means the separation of suspended solids from the water by filter fabrics, membranes or layers of porous filter material. It is powered by the pressure gradient between the suspension and the filtrate side, which presses the water through the filter. Wastewater treatment filters can be distinguished by various attributes [ECKHARDT, HERMANN and MEYER, 2010]:

- Filter velocity (slow and quick filters)
- Rinsing capability (rinsable/non-rinsable filters)
- Construction (open, closed)
- Material phases (overflooded/wet filter, dry/trickle filters)
- Flow direction (upstream/downstream flow)
- Layer build-up (one- or multi-layer filters)

Non-vegetated *sand filter* bodies consist of washed filter sand with special grain size distribution, particle shape and calcium content, optionally covered with a layer of fine gravel [ASTRA and BAFU, 2010; quoted by PFEFFERMANN, 2011]. Sand filters that are mostly applied in stormwater treatment are so-called “slow filters” with a filter velocity of approx. 0.05 to 0.2 m/h. The filter performance is influenced by a biofilm of fine sediments, organic compounds and microbes that develops from the water passage through the filter body. Organic substances are biodegraded [ECKHARDT, HERMANN and MEYER, 2010]. Nevertheless, the top layer of 50 to 75 mm must be removed regularly to prevent clogging of the filter and the resulting decrease of the filter performance. Some quicker sand filters, mostly used in urban wastewater treatment and the combined sewage system, are regularly backwashed by pumping water or a mixture of air and water through the filter body in opposite direction. This process finds expression in temporarily lower filter performance, resp. higher pollutant concentrations, which is why the backwash water must be captured and must not be discharged immediately into the receiving water to avoid deterioration. So far, there has not been much experience in the application of quick sand filters in stormwater, resp. highway runoff treatment. [ASTRA and BAFU, 2010; quoted by PFEFFERMANN, 2011]

On account of their similar functionality, *pile fabric filters* and *micro filters* are discussed in one section. Both filtration systems are used to remove fine particles and particulate heavy metals from highway runoff. The water is filtered through pile woven fabric (pile fabric filtration) or fine polymer or metal meshes (micro filtration) with a diameter of 6 to 500 µm. Pile fabric filters are cleaned with a suction mechanism to prevent clogging, while micro filters are cleaned with high pressure nozzles and precedent suction of the sludge. [ASTRA and BAFU, 2010; quoted by PFEFFERMANN, 2011]

Membrane filtration separates wastewater into purified water (permeate) and the retained solids, colloids or dissolved substances (concentrate) by a separating layer, the membrane. This process is powered by the pressure gradient between the permeate side and the concentrate side. Although very effective, membrane filtration is scarcely applied in highway runoff treatment on account of the high costs that are involved. It is mostly used in drinking water purification. Nevertheless the implementation of membrane filtration in highway runoff treatment is possible and effective, since phase separation up to the molecular range can be achieved, depending on the design, separation limit, structure and operation mode of the applied membrane modules. Possible separation limits are micro filtration (particle diameters of > 0.1 µm, removal of suspended solids, bacteria, colloids and algae), ultra filtration (0.1 – 0.01 µm, removal of colloids, macro-molecules and viruses), nano filtration (0.01 – 0.001 µm, removal of organic compounds and divalent ions) and reverse osmosis (< 0.001 µm removal of monovalent ions). [ECKHARDT, HERMANN and MEYER, 2010]

There are various pilot projects and systems for technical filtration of road runoff, which cannot be discussed extensively in this term paper. Mostly, convertible filter elements (filter bags or cartridges) are inserted into existing road gullies and filter shafts. Alternatively, there are more complex filter-shaft-systems with buid-in filters available on the market. These systems possess small sludge traps as treatment stage preliminary to the multi-layered filter body, which must be emptied in regular intervals, while the (retro-fitted) convertible filter elements must not be replaced as often. In case of clogging the filter systems are equipped with an overflow device. Technical filtration applies especially for small runoff catchment areas (f. e. truck parking lots). [BROMBACH and WEIß, 2007]

3.2.4 Nature-orientated treatment

The natural water balance provides a certain amount of evaporation and percolation for groundwater recharge, while surface runoff shows the lowest rates under natural conditions, as illustrated in figure 15. The sealing, paving and developing of wide areas and the collection and discharge of runoff water into common sewage systems throws this natural water cycle out of balance.

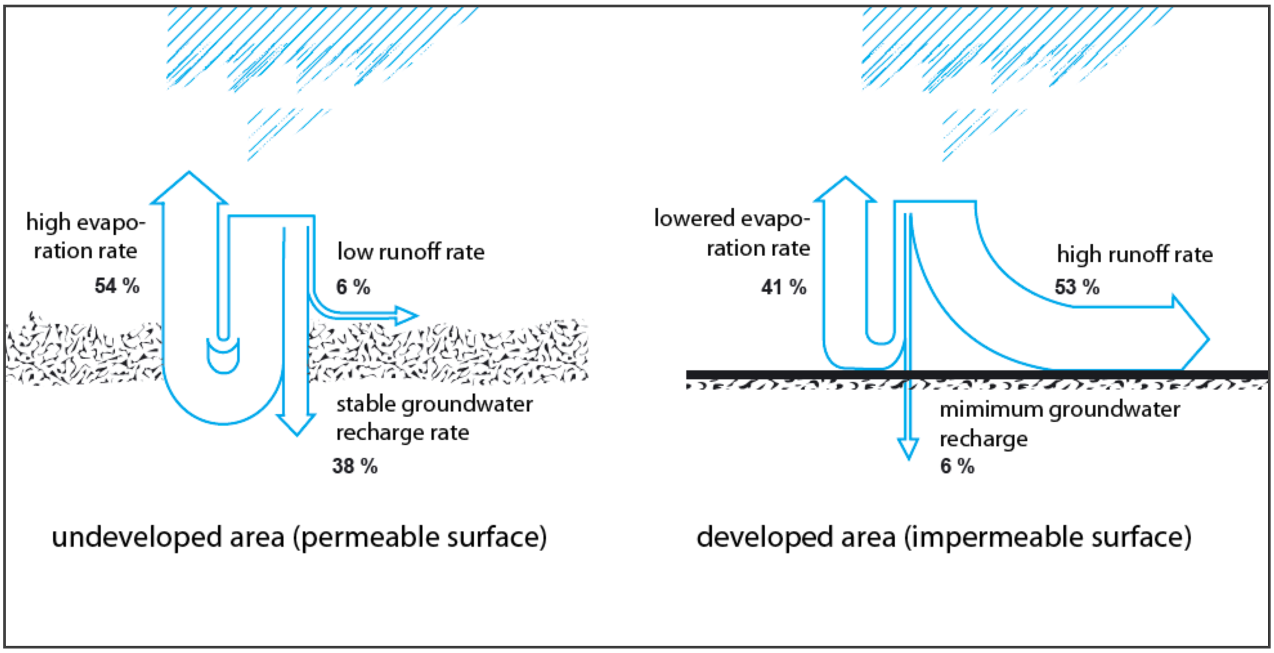

Fig. 15: Natural water balance (left) and anthropogenic modified water cycle (right), modified according to [MUGV, no year]

Nature-orientated treatment comprises all treatment measurements that promote direct evaporation or percolation of stormwater as well as careful draining of stormwater that was filtered by topsoil or vegetated filter substrate into receiving waters.

As seen in the previous chapters and the requirements of the Federal Water Act [§ 55 WHG], decentralized extensive percolation of road runoff is preferable to centralized treatment, given that no pre-treatment is required and harmful effects on groundwater and receiving waters are not to be expected. Extensive percolation requires a certain amount of space, which is not always viable in practice. Therefore, other percolation systems like trough percolation, the combination of trough and trench percolation or infiltration tanks can be applied.

The effectiveness of highway runoff treatment by percolation depends on the soil structure, the thickness of topsoil layer and the vegetation. Also, the height of the groundwater table is important, since water cannot be percolated through saturated soil zones. A distance of at least 1 m to the mean groundwater level is required. As seen in section 2.3.2 of this term paper, the soil must possess a certain infiltration capacity necessary to a certain clearing effect ($k_f = 10^{-3}$ m/s – 10^{-5} m/s). The vegetated top soil should be about 20 cm thick. [RAS-Ew, 2005; quoted by PFEFFERMANN, 2011]

Table 18 shows the infiltration capacity of different percolation methods.

Percolation method	**Infiltration capacity**
Water-permeable paving of road surfaces (compacted)	$k_f > 5.4 \bullet 10^{-5}$ m/s
Extensive percolation (not compacted)	$k_f > 2.0 \bullet 10^{-5}$ m/s
Trough percolation	$k_f > 1.0 \bullet 10^{-5}$ m/s
Trough-trench percolation (without drainage)	$k_f > 0.1 \bullet 10^{-5}$ m/s
Tank percolation	$k_f > 1.0 \bullet 10^{-5}$ m/s

Tab. 18: Guide values for the choice of a percolation method according to the FGSV [PFEFFERMANN, 2011]

For *extensive percolation*, the hydraulic permeability should not be lower than $k_f = 10^{-3}$ m/s to guarantee the absorption and percolation of road runoff in case of heavy rainfall events, since there is not water storage capacity. [PFEFFERMANN, 2011]

By contrast, *trough percolation* requires less space as well and the trough provides temporary above-ground storage capacity for stormwater. Also, trough percolation can be applied for soils with a lower k_f-value than 10^{-3} m/s. The necessary pore volume is obtained by vegetation, mostly landscaped lawn. Some troughs are also planted with shrubs, small trees or reed, dependent on the location. The depth of the trough should not exceed one fifth of the width. [PFEFFERMANN, 2011]

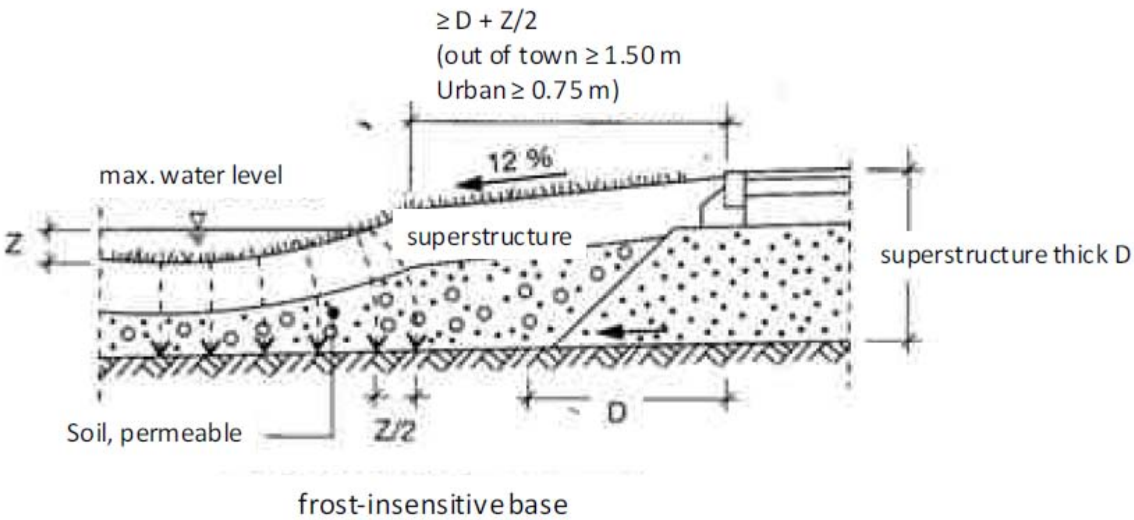

Fig. 16: Road embankment and trough construction at frost intensive base with required minimum distance from the road superstructure [PFEFFERMANN, 2011]

At trough-trench percolation a trench pipe is fitted beneath the trough as additional storage capacity (as seen in figure 17). The trench is also connected with the trough overflow that must be applied if the percolation area is less than 10 % of the connected paved area. The drained water can be percolated belowground or discharged, depending on the infiltration capacity. More information on design, dimensioning and construction of trough and trough-trench percolation systems is given in the worksheet DWA-A 138. [PFEFFERMANN, 2011]

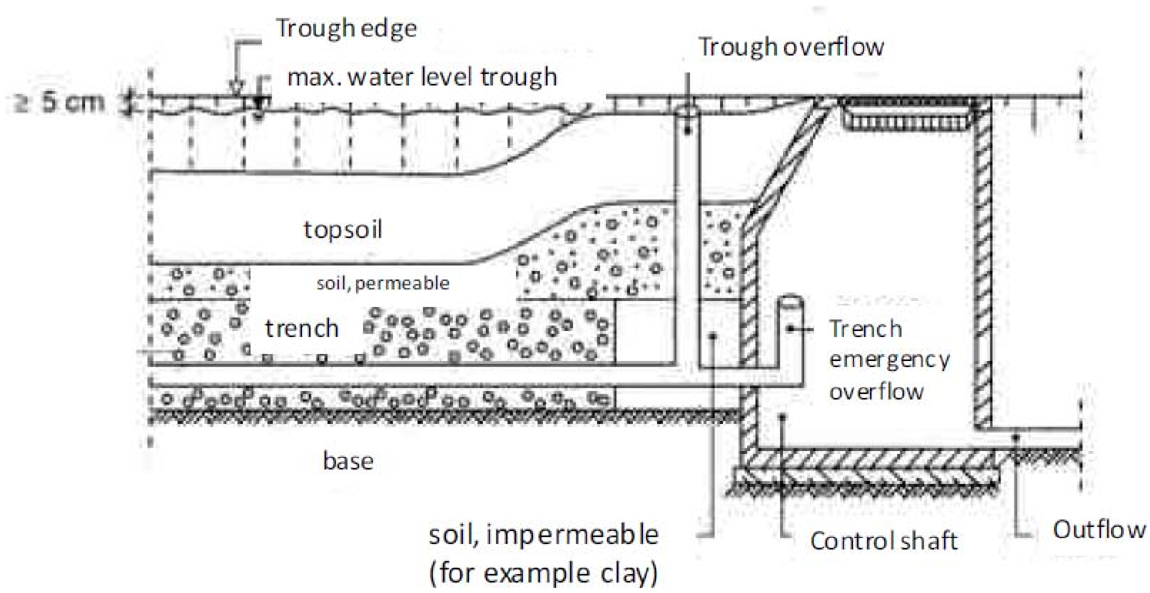

Fig. 17: Trough-trench percolation system in soil with a low storage capacity [PFEFFERMANN, 2011]

However, highly polluted road runoff (especially with limited space abailability) requires centralized treatment precedent to percolation or discharge into receiving waters, which is accomplished in a nature-orientated way by *retention soil filters*.

Alongside constructed wetlands[99] retention soil filters have been successfully applied for wastewater treatment in the combined sewage system. Recently retention soil filters have also been used for the physical-biological treatment of stormwater, which is researched thoroughly in the project work of Dipl.-Ing. Julia Rempp.

Retention soil filters remove high amounts of pollutants. Another advantage is the hydraulic water retention, resp. discharge delay.

The different removal processes that become effective in retention soil filters are the sedimentation of solids, the filtration of spare particles and particle-bound substances and the sorption and biochemical conversion of dissolved substances. Usually, retention soil filters are built with an upstream sedimentation tank with additional light

[99] Pflanzenkläranlage

liquid separator (precursor) to clarify the runoff water preliminary and prevent the clogging of the filter. The filter body is fitted into a sealed filter tank. It consists of filter sand (layer thickness approx. 0.75 m to 1m), drainage and a control outlet. The surface is vegetated to obtain the necessary pore volume and prevent clogging. Mostly, reed (*Phragmites australis*) is planted. [PFEFFERMANN, 2011]

After passing the sedimentation tank the stormwater percolates through the filter, is drained and discharged afterwards. On account of the clogging risk, the aspired impounding depth should not be exhausted[100] permanently. The permanent storage depth of the sedimentation tank levels with the surface of the filter bed (see also fig. 18). Yet, in some cases retention soil filters are permanently impounded to establish the reed vegetation [Roth-Kleyer, 2010; quoted by PFEFFERMANN, 2011]

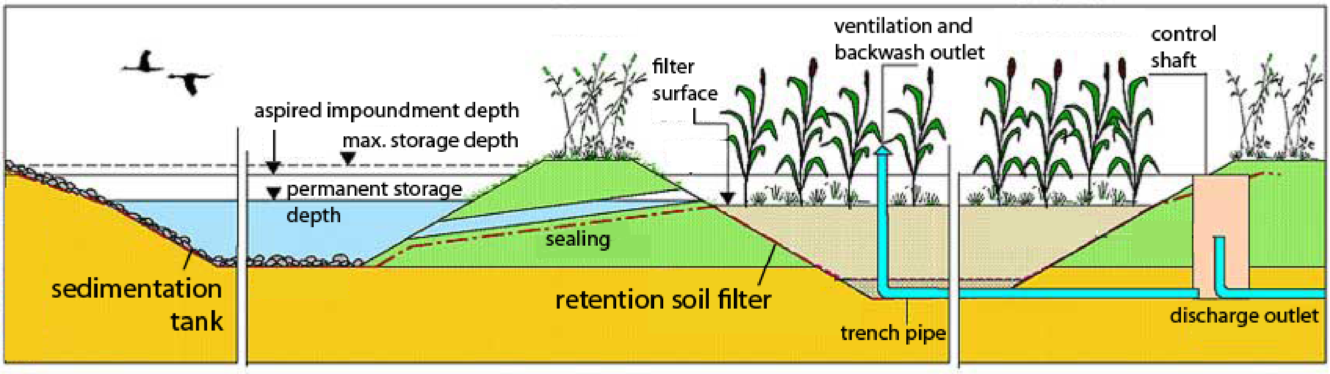

Fig. 18: Section of retention soil filter with upstream sedimentation tank [OEKOTEC, URL; 02/26/2012]

3.2.5 Special treatment systems

Highway runoff, especially from highly frequented sections (f. e. in urban agglomeration areas or along important roadway connections), is mostly heavily contaminated with various pollutants (as seen in section 3.1 of this term paper) and cannot be discharged into receiving waters or percolated without pre-treatment. In addition to the common treatment systems like sedimentation tanks, separators or

[100] hier: ausgereizt

retention soil filters, several decentralized procedures and special treatment systems can be applied [PFEFFERMANN, 2011]:

- Pavement with filtration effect
- Screen, geotextile or air filter inserts, mostly in combination with sedimentation systems and light liquid separators

Some special treatment systems are precisely described by PFEFFERMANN (2011), naming patented models, their functioning, clearing efficiency and costs.

3.3 Best practice

Within the framework of the European „DayWater"-Project[101] and a European project concerned with the treatment and evaluation of priority hazardous substances of the European Water Framework Directive in wastewater ("ScorePP-Project") a study on the "priority pollutant behaviour in stormwater Best Management Practices (BMPs)" was carried out by a group of scientists [SCHOLES et alii, 2008] in collaboration with the "Institute of environment and resources" of the Technical University of Denmark in 2007. The objective of the study was the development of a "theoretical approach" to the assessment of priority hazardous substances and their removal potentials in different BMPs, since only little practical expertise and monitoring data, especially regarding "best practice", can be found.

[101] The „DayWater"-Project is a scientific project of the 5th European framework program (EVK1-2001-00242) that develops an "Adaptive Decision Support System" (ADSS) for urban stormwater management. The ADSS intends the computer-aided integration of decentralized stormwater handling in urban waste-and stormwater management in 8 European countries. "Daywater" is an adaption of the Swedish word "Dagwaten", which means stormwater or surface runoff. Ten institutions (Universities, laboratories, companies and individual scientist) from Sweden, Denmark, Germany, Netherlands, Great Britain, France, Greece and the Czech Republic participate in the project. [DAYWATER, URL; 02/23/2012], [SIEKER, URL; 02/23/2012]

In the first step, primary removal processes were identified in the 15 BMPs

- Filter drains
- Porous asphalt
- Porous paving
- Filter strips
- Swales (trough percolation)
- Soakaways
- Infiltration trenches
- Infiltration basins
- Sedimentation tanks
- Retention ponds
- Detention basins
- Extended detention basins
- Lagoons
- Constructed wetlands with sub-surface flow (ssf) and
- Constructed wetlands with surface flow (sf).

The primary removal processes can be distinguished in two types. Firstly, there are direct removal processes, which result directly in the removal of the pollutant from the water:

- Settling
- Filtration
- Volatilization
- Adsorption to substrate
- Photolysis
- Plant uptake
- Microbial degradation

Also, there are indirect removal processes, which make dissolved pollutants bind to solids or form bigger units. These indirect processes require subsequent primary processes to effectively remove the pollutants from the water. Nevertheless, they make the application of direct removal processes possible in the first place, since most direct removal processes do not effectively apply for dissolved pollutants. Indirect removal processes are: adsorption to suspended solids, chemical precipitation and Flocculation (coagulation). The primary removal processes were assessed by their applicability to the BMPs, as seen in table 19.

	Adsorption to substrate	**Settling**	**Microbial degradation**	**Filtration**	**Volatilization**	**Photolysis**	**Plant uptake**
Filter drain („French drain“)	H/M	M/L	M	M	L	N.A.	L
Porous asphalt	M/L	L	L	H	L	L	N.A.
Porous paving	H	M/L	M	H	L	N.A.	L
Filter strip	M	L	M/L	M/L	M/L	M/L	M
Trough percolation („swales“)	M	M/L	M/L	M	M	M/L	M
Soakaways	H/M	M/L	M	H/M	L	N.A.	L
Infiltration trench	H/M	M/L	M	H/M	L	N.A.	L
Infiltration basin	H	H	H	H/M	M	M/L	L/M
Sedimentation tank	L	H/M	L	N.A.	L	L	N.A.
Retention ponds	M/L	H	M	L	M	M/L	L
Detention basins	M	H/M	M/L	L	M	M/L	L
Extended detention basins	M	H	M	L	M	M/L	L
Lagoons	M/L	H/M	L	L	M/L	L	L
Constructed wetlands (ssf)	H/M	M	H	H/M	M/L	L	H/M
Constructed wetlands (sf)	M	M	M	M	M	L	M
H High							
H/M High to medium							

M	Medium
M/L	Medium to low
L	Low
N.A.	Process is not applicable to the treatment mechanism

Tab. 19: Relative importance of the primary processes of pollutant removal to the treatment mechanisms (facility types) [modified according to SCHOLES et alii, 2008]

In the second step, 52 pollutants, comprising the priority hazardous substances listed by the Water Framework Directive as well as representative pollutant group members, were assessed by their physio-chemical properties (and, where data were missing, by expert judgment) to identify their respective potential of being eliminated by different removal processes. Table 20 shows the removal potential of selected, traffic-related priority hazardous substances (see also section 3.1 of this term paper) by the processes of photolysis, volatilization, bioaccumulation (plant uptake) and microbial degradation. The possible interactions between direct and indirect removal processes can be seen in table 21, which shows the removal potential of pollutants by a combination of chemical precipitation and adsorption to suspended solids and subsequent settling or filtration.

Substance group	**Substance**	**Removal potential by photo-lysis**	**Predicted volatility level**	**Predicted plant uptake level**	**Removal potential by microbial degradation**		
					aerobic	**anaerobic**	**overall**
PAH and benzene	Benzene	L	H	L	H	L	M
	Anthracene	H	M	M	H/M	-	M/L
	Fluoranthene	M	M	H/M	M	L	M/L
	Benzo(a)pyrene	H	M/L	H	L	L	L
	Benzo(g,h,i)perylene	H	M/L	H	L	L	L
	Indeno(1,2,3-cd)prene	H	M/L	H	L	-	L
	Benzo(k)fluoranthene	H	M/L	H	L	L	L
	Benzo(b)fluoaranthene	H	M	H	L	L	L
Chlor-	1,2,4-trichlorbenzene	L	H	M	H/M	M/L	M

benzenes	Trichlorbenzenes	L	H	M	L	L	L
Endocrine disrupters	Octylphenols	L	M	M	H	-	-
	Nonylphenols	H	M	H/M	H	H/M	H/M
	Bis(2-ethylhexyl)phthalates (DEHP)	L	M	H	H	M/L	M
Heavy metals	Cadmium compounds	N.A.	N.A.	L	N.A.	L	L
	Lead compounds	N.A.	N.A.	L	N.A.	L	L
	Nickel compounds	N.A.	N.A.	L	N.A.	L	L

H	High
H/M	High to medium
M	Medium
M/L	Medium to low
L	Low
N.A.	Process is not applicable for the substance
-	No data available

Tab. 20: Potential for pollutants to be removed by the direct processes photolysis, volatilization, plant uptake and microbial degradation (aerobic and anaerobic) [modified according to SCHOLES et alii, 2008]

Substance group	Substance	Tendency to adsorb to suspended solids	Tendency to chemical precipitation	Overall potential for removal
PAH and benzene	Benzene	M/L	M	M
	Anthracene	H/M	H	H
	Fluoranthene	H/M	H	H
	Benzo(a)pyrene	H	H	H
	Benzo(g,h,i)perylene	H	H	H
	Indeno(1,2,3-cd)prene	H	H	H
	Benzo(k)fluoranthene	H	H	H
	Benzo(b)fluoaranthene	H	H	H
Chlorbenzenes	1,2,4-trichlorbenzene	M	H	H/M
	Trichlorbenzenes	M	H	H/M
Endocrine disrupters	Octylphenols	M	H	H/M
	Nonylphenols	H/M	H	H
	Bis(2-ethylhexyl)phthalates (DEHP)	H	H	H
Heavy metals	Cadmium compounds	L	M	L
	Lead compounds	H	H/M	H
	Nickel compounds	M	M	M
H High H/M High to medium M Medium M/L Medium to low L Low				

Tab. 21: Potential for pollutants to be removed by settling and filtration (direct process) on account of combined effects of adsorption to suspended solids and chemical precipitation (indirect processes) [modified according to SCHOLES et alii, 2008]

The project work [SCHOLES et alii, 2008] provide a lot of detailed data on the various processes, the physio-chemical assessment of the pollutants and the intermediate steps of the calculation, which could not be transferred completely here, since they would be beyond the scope of this term paper.

In the third step, the information about the significance of the removal processes to the BMPs and the susceptibility of the pollutants to the removal processes were combined. SCHOLES et alii (2008) used a method similar to a risk-rating approach, which transformed the classifications that were set in the precedent steps (high, high to medium, medium, medium to low and low and not applicable) into ordinal values (3, 2.5, 2, 2.5, 1 and 0). The relative importance of the direct removal processes to an individual BMP (table 22 column 2, exemplarily for the infiltration trench) as well as the significance of the removal processes to an individual pollutant (table 22 column 3, exemplarily for benzene) were expressed with those ordinal values. By addition or multiplication (depending on the approach) combined values were generated for each removal process (table 22 column 4). The overall value (generated by addition of the combined values for every removal process) reveals the removal potential of the individual pollutant by the individual BMP, f. e. the removal potential of benzene in an infiltration trench, as seen in table 22.

Removal process	Significance of process to BMP	Significance of process to pollutant	Combined value
Adsorption to substrate	2.5	1.5	3.75
Settling	1.5	2	3
Microbial degradation	2	2	4
Filtration	2.5	2	5
Volatilization	0.5	3	1.5
Photolysis	0	1	0
Plant uptake	1	1	1
		Overall value	**18.25**

Tab. 22: Potential for the removal of benzene by an infiltration trench (combined value by multiplication) [Scholes et alii, 2008]

By repeating this procedure for each BMP, the BMPs can be ranked by their overall values. Thos ranking shows the “order of preference” of BMPs to remove an individual pollutant. For benzene, this ranking is shown in table 23.

BMP	Overall value	Ranking position
Infiltration basin	26.75	1
Constructed wetland (ssf)	24	2
Constructed wetland (sf)	20.5	3
Porous paving	20	4
Extended detention basin	19.75	5
Retention pond	19	6
Trough (swale)	18.75	7
Infiltration trench	18.25	8.5
Soakaway	18.25	8.5
Detention basin	17.75	10
Filter drain	17.25	11
Filter strip	16	12
Logoon	15	13
Porous asphalt	14.25	14
Settlement tank	10.5	15

Tab. 23: Ranking of BMPs for the removal of benzene [SCHOLES et alii, 2008]

Since the allocated values are ordinal, not numeric, the ranking is valid only for the assessment of pollutant removal in relation to other BMPs. The values do not express an actual pollutant removal rate. SCHOLES et alii (2008) performed this procedure for all of the 52 pollutants and generated various figures of BMP rankings for the removal potentials of different substance groups, of which the most important (concerning the traffic-related priority hazardous substances) are listed in annex 2 of this term paper.

Summarizing all evaluated pollutants, the infiltration basins performed best, closely followed by the constructed wetlands with sub-surface flow. This good results throughout the study is likely to go back to the fact that all removal processes, direct and indirect, are possible to occur in infiltration basins as well was sub-surface flow constructed wetlands. Porous asphalt and settlement tanks exhibited the poorest results for all evaluated pollutants.

4. Selection methods

The selection of an appropriate treatment method depends from various factors. Technical, environmental, social/urban and economic interests mingle in the decision process. [ELLIS et alii, 2004]

First and foremost the protection of water resources and environment are important. This puts demands on the efficiency and cleaning effect of the treatment methods. Filtration through the vegetated top soil performed best in many studies and is not without reason recommended by most water management associations and water laws. In Germany the most promoted treatment method is the decentralized percolation, either extensive over the embankments or through the top soil of troughs. It is likely that the federal states, which do not mention this method explicitly, also percolate most of the highway runoff decentralized [PFEFFERMANN, 2011]. This concurs with the fundamental principles of wastewater abatement according to the Federal Water Act[102], which say that stormwater should be percolated or irrigated decentralized whenever possible or collected in a separate sewage system (stormwater channel) and discharged into nearby receiving waters, unless there are opposing water management regulations or public interests. This generally means that, as long as the standards and legal obligations are met, decentralized percolation is the treatment method of choice.

Yet, another factor is the availability of space and permeable surface. Also, the type and structure of soil is important, since soil needs to fulfill special criteria (f. e. k_f-value, thickness) to be a suitable percolation area that is able to restrain pollutants. As already pointed out in this term paper, centralized treatment methods only apply when the space requirements of extensive or trough percolation exceed the surface available for possible treatment. According to PFEFFERMANN (2011) the most often used centralized treatment methods in Germany are stormwater holding tanks, stormwater sedimentation tanks and RiStWag separators. Occasionally there are combined systems of stormwater holding tanks and downstream percolation tanks.

[102] § 55 WHG

Filtration systems and lamella separators can be found rather in urban areas, resp. the highway runoff treatment facilities in city states (Berlin, Bremen, Hamburg). Throughout the Federal Republic of Germany retention soil filters and other percolation systems probably are the exception [PFEFFERMANN, 2011].

Apart from the available space and the demands on the water quality (and thus the pollutant retention performance of the treatment system) the quantity of treatment-requiring stormwater must be regarded. Also, the reliability and durability of the system, the flexibility to retrofitting and the operability as well as the costs for acquisition, building and maintenance are important criteria. [ELLIS et alii, 2004]

A group of British and French scientists carried out a study on “multicriteria decision approaches to support sustainable drainage options for the treatment of highway and urban runoff” in 2004 and developed primary and secondary criteria as well as benchmark standards for the categories “technical and scientific performance” “and “economic costings”, as seen in table 24. The categories “environmental impacts” and “social and urban community benefits” were addressed as well, but the primary and secondary criteria that can be set for those two categories are closely interlinked with the criteria of the scientific/technical performance and the economic costs, since f. e. low costs and efficient treatment facilities that are flexible to retrofitting and easy to handle provide community benefits or an excellent system performance and reliability provides protection of the environment by keeping the pollutant concentrations below the limit values.

	Technical and scientific performance	Economic costs
Primary criteria	System performance (a)	Life cycle costs (a)
	System reliability (b)	Financial risks (b)
	System durability (c)	Affordability (c)
	System flexibility (d)	
Secondary criteria	Flooding and storage, aspired receiving water quality (a)	Investment and operational costs (a)
	Performance reliability, provisions health and safety (b)	Risk exposure (b)
	Design life (c)	Long-term affordability (c)
	Capability for change (retrofitting) (d)	
Benchmark standards	Precipitation data resp. number of floods/year, pollutant concentrations (influent/effluent) and pollutant degradation rates, disruption costs/time, “first flush”-capture potential, in-basin quality etc. (a) + (b)	Design and capital costs, operational and maintenance costs, sediment disposal costs, monitoring costs, decommissioning costs (a)
	Operational lifetime (storage volumes, sediment accumulation etc.) (c)	Cost-benefit analysis, investment loss risk, operational health and safety risks etc. (b)
	Costs and ease of retrofitting and/or add-on structures/features (d)	Adoption and liability coverage, economic add-on value (incl. land/property value), long-term management, provision and costs (c)

Tab. 24: Primary/secondary criteria and benchmark standard proposals for the assessment and selection process of appropriate and sustainable highway and urban runoff treatment facilities [modified according to ELLIS et alii, 2004]

The selection process of the developed “multicriteria decision approach” is shown in figure 19.

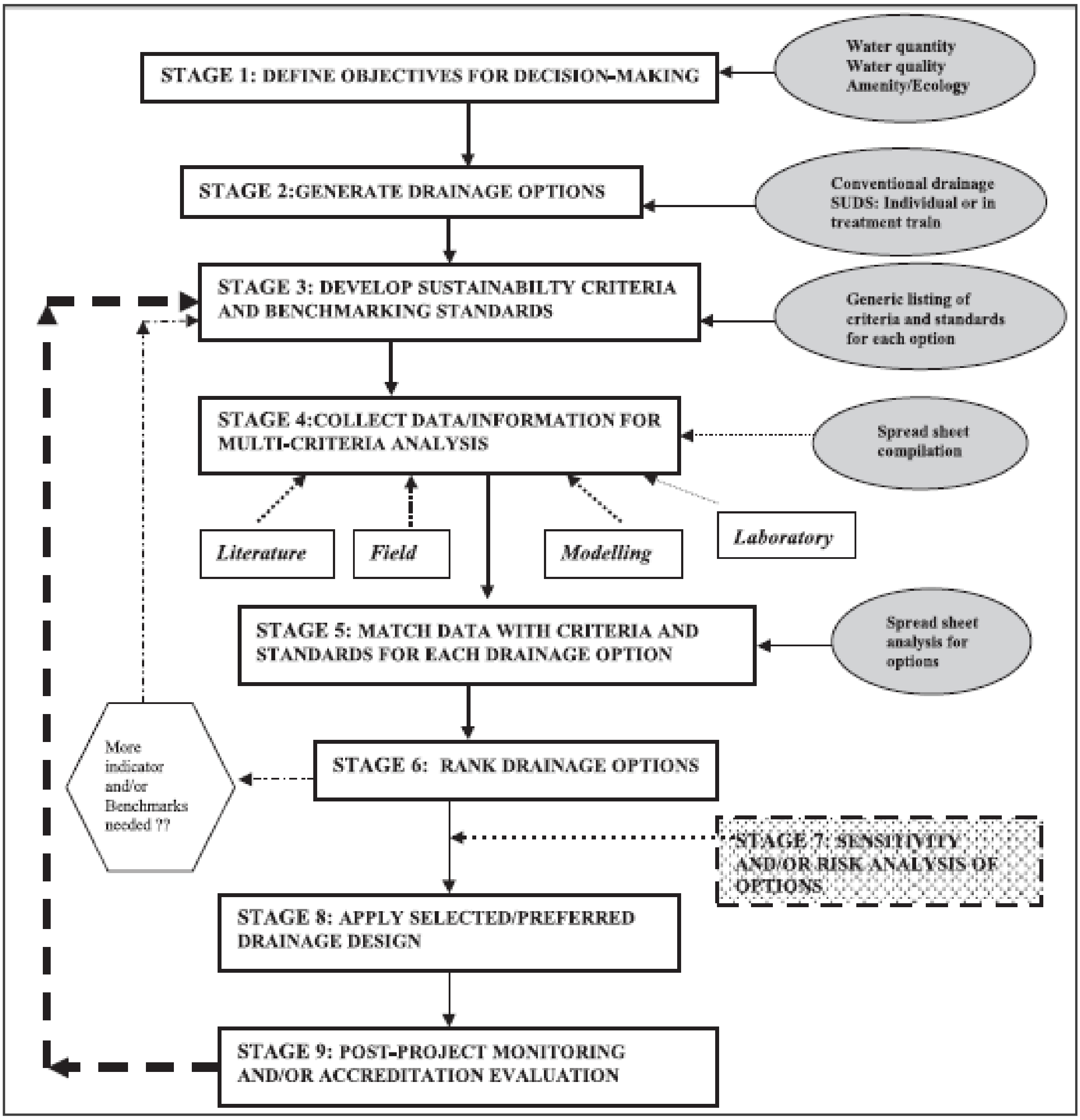

Fig. 19: Workflow chart of the evaluation of urban and highway runoff control and treatment options [ELLIS et alii, 2004]

The research of a “multicriteria decision approach” proposes a lot of criteria that are flexible and applicable to various circumstances. Nevertheless, the mixture of quantitative and qualitative measures (some quantifiable, some rather argumentative in nature) can cause difficulties in the selection process.

It can be stated that selection processes for urban runoff treatment facilities is mostly more complicated than the selection of highway runoff treatment facilities due to the scarce available space, the higher aesthetical demands on the planning and the possibility of heterogeneous contamination of runoff water (depending on the areas connected to the stormwater channel in separate sewage systems) in urban agglomeration areas. For highway runoff drainage systems “the technical and scientific performance criteria might be the principal drivers” of the selection process [ELLIS et alii, 2004].

4.1 Baden-Wurttembergs solution

The evaluation method for the selection of road runoff treatment facilities in Baden-Wurttemberg is based on the advisory leaflet DWA-M 153 and the principles of the “technical rules for the discharge and treatment of road runoff”[103] (2008) and is described in annex 2 of the latter technical rules.

[103] Technische Regeln zur Ableitung und Behandlung von Straßenoberflächenwasser

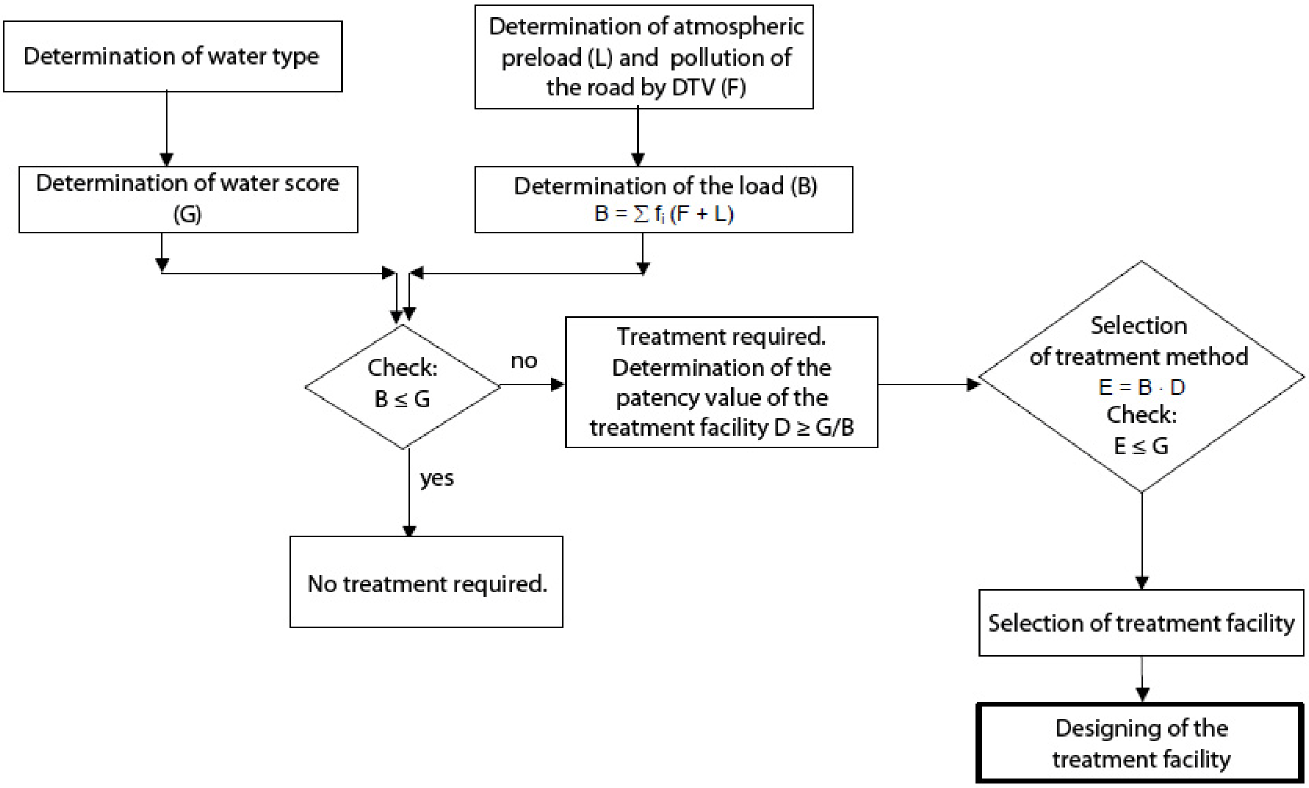

Fig. 20: Workflow chart of the selection method according to annex 2 of the "Technical rules for the discharge and treatment of road runoff" Baden-Wurttemberg [KARLSRUHE REGIONAL COUNCIL, 2008]

Figure 20 shows the workflow of the selection method. The particular steps will be explained in the following.

The DWA guidelines and DWA-M 153 were introduced in section 2.3 "technical guidelines and standard specifications". Baden-Wurttembergs selection method for appropriate runoff treatment measurements in road planning and construction processes is closely orientated towards DWA-M 153. Table def (2.3) showed the contamination categorized by the origin of runoff exemplarily for the scoring system. Baden-Wurttemberg has taken over this system just for the categorization of road runoff by the daily traffic volume, as seen in table 25. This is one factor (F) in the calculation that leads to the selection of an appropriate treatment method. Further, there is the determination of the atmospheric preload (L) of dust and fine particulate air pollution, as seen in table 26. Since the atmospheric preload outside of urban areas is negligible, the score point is 1.

From factor F and L the load of runoff (B) can be calculated:

$$B = \sum fj\ (L + F)$$

with: $\sum fj$ = total area

L = atmospheric preload (table 26)

F = road pollution (table 25)

Pollution load from the area (F)			
Contamination	**Exemplary origin areas**	**Type**	**Points**
Medium	Roads with a DTV of 300 – 5,000 vehicles/24h f. e. local roads	F4	19
	Roads with a DTV of 5,000 – 15,000 vehicles/24h f. e. Federal roads with one lane in each direction	F5	27
High	Roads with a DTV exceeding 15,000 vehicles/24h f. e. highways and federal roads with two lanes in each direction	F6	35
	Highly frequented truck access roads in commercial, industrial or comparable areas	F7	45*
* Percolation only allowed with control option after cleaning			

Tab. 25: Determination of the road pollution by DTV, according to the scoring system of the DWA-M 153 [KARLSRUHE REGIONAL COUNCIL, 2008]

Atmospheric preload (dust, fine particles) (L)			
Contamination	**Exemplary origin areas**	**Type**	**Points**
Low	Roads outside of urban areas	L1	1

Tab. 26: Determination of the atmospheric preload outside of urban areas, according to the scoring system of the DWA-M 153 [KARLSRUHE REGIONAL COUNCIL, 2008]

Another relevant factor is the “water score” (G)[104], which categorizes the receiving waters in water types and assigns them with score points. This categorization and scoring expresses the resilience of receiving waters, which depends on the size of

[104] Gewässerpunktezahl

the receiving waters as well as on the flow velocity. The water score is to allocate by table 27/a and 27/b, which were taken over from the DWA-M 153 without modification. In the annex 2 of the "technical rules for the discharge and treatment of road runoff" it is noted that similar waters that cannot be found in this listing should be categorized analogously.

Water resilience score (G)			
Water type	**Exemplary receiving waters**	**Type**	**Points**
Flowing waters	Large river (MQ > 50 m^3/s)	G2	27
	Small river (b_{Sp} > 5 m)	G3	24
	Large hill/mountain stream (b_{Sp} 1 – 5 m, v ≥ 0.5 m/s)	G4	21
	Large lowland stream (b_{Sp} 1 – 5 m, v ≥ 0.5 m/s)	G5	18
	Small hill/mountain stream (b_{Sp} < 1 m, v ≥ 0.3 m/s)		
	Small lowland stream (b_{Sp} < 1 m, v < 0.3 m/s)	G6	15
Water reservoirs and bodies of standing water	Large lake (surface > 1 km^2) or Storage reservoir of a large river (MQ > 50 m^3/s)	G7	18
	Storage reservoir of a small river	G8	16
	Storage reservoir of a large hill/mountain stream	G9	14
	Storage reservoir of a large lowland stream	G10	12
	Small lake or pond	G11	10
Groundwater	Outside the ambit of a drinking water catchment area	G12	10
	Karst areas without connection to a drinking water catchment area (requires proof)	G13	8
b_{Sp} = mean width of water level (German: Mittlere Wasserspiegelbreite) v = flow velocity MQ = mean discharge (German: Mittelwasserabfluss)			

Tab. 27/a: Determination of the water resilience, resp. water scores, according to the scoring system of the DWA-M 153 [KARLSRUHE REGIONAL COUNCIL, 2008]

Water resilience score (G)			
Water type	**Exemplary receiving waters**	**Type**	**Points**
Flowing waters	Less than 2 hours MQ-flow time* before reaching the next water protection area	G21	14
	Less than 2 hours MQ-flow time* before reaching the next small lake		
	Discharge within the ambit of a water protection area	G22	11
	Bathing waters		
Bodies of standing water or flowing waters with an extremely low flow velocity	Discharge into a lake in close proximity to recreational areas	G23	11
	Flow velocity lower than 0.1 m/s at MQ	G24	10
Groundwater	Water protection zone III B	G 25	≤ 8 **
	Water protection zone III A	G26	≤ 5 **
	Karst areas without connection to a drinking water catchment area (requires proof) or Water protection zone II ***	G27	≤ 3 **
Particularly sensitive water bodies	Water protection zone I	G 28	0 ***
	Water bodies with the water quality class I (determined by Federal Water Act) or fountainhead regions		
* MQ-flow time = flow time at mean discharge (German: Fließzeit bei Mittelwasserabfluss) ** requires individual case assessment *** requires exceptional permission resp. exemtion from the sanctuary ordinance **** generally no discharge permitted			

Tab. 27/b: Determination of the water resilience, resp. water scores with special regards to areas, according to the scoring system of the DWA-M 153 [KARLSRUHE REGIONAL COUNCIL, 2008]

Having introduced the scoring of runoff load [i. e. $B = \sum fj \ (L + F)$] and the scoring of water resilience [G], the first decision on whether treatment is needed or not can be made by comparing the B and G score.

If the runoff load is equal to the water resilience or lower, no treatment is required (see also fig. 20). If the runoff load score exceeds the water resilience score the runoff must be treated. This leads to the next step: the actual selection of an appropriate method.

For this, another factor is needed to express the patency value[105] of the treatment methods. This patency value is allocated by two other tables (28/a and 28/b).

Patency value of soil passage (D)					
Example	**Type**	**Proportion from non-permeable area (A_U) to percolation area (A_S)** **$A_U : A_S$**			
		A	**b**	**C**	**D**
Percolation through 30 cm vegetated top soil	D1	0.1	0.2	0.45	*
Percolation through 20 cm vegetated top soil	D2	0.2	0.35	*	*
Percolation through 15 cm vegetated top soil	D3	0.4	-	-	-
Soil passage (by trough percolation) through extensive topset beds** of 3 – 5 m thickness and 10^{-3} m/s – 10^{-6} m/s soil permeability (k_f-value)	D4	0.35	0.45	0.6	0.8
Extensive percolation without regards to further soil passage through trench percolation / ballast bed*** or topset beds thinner than D4	D6	1.0			
* permeability is insufficient for the expectable hydraulic stress, application of this soil passage is not sensible due to the high risk potential, should only be applied in special cases ** German: flächenhaft durchgehende Deckschichten *** German: Schotterbett					

Tab. 28/a: Determination of the patency value of top soil in percolation facilities, according to the scoring system of the DWA-M 153 [KARLSRUHE REGIONAL COUNCIL, 2008]

105 Durchgangswert

Patency value of sedimentation and filtration facilities (D)					
Example	**Type**	**Design**			
		a	**B**	**C**	**D**
Soil filtration facilities*	D21	**	0.36	0.3	0.25
Facilities with clearance after precipitation event and a maximum of 7.5 m/h surface feeding*** by r_{crit} **** f. e. stormwater sedimentation tanks without permanent storage	D22	0.48	0.36	0.3	0.25
Facilities with permanent storage or permanent flow and a maximum of 7.5 m/h surface feeding by r_{crit} f. e. stormwater sedimentation tanks	D24	0.58	0.45	0.38	0.3
Design explanation: **a = 50 % retention of solids (annual average)** i. e. r_{crit} = 15 L/(s• ha) **b = 60 % retention of solids (annual average)** i. e. r_{crit} = 30 L/(s• ha) **c = 65 % retention of solids (annual average)** i. e. r_{crit} = 45 L/(s• ha) **d = 70 % retention of solids (annual average)** i. e. r_{crit} = 60 L/(s• ha)					
* depending on the structure of the individual facilities, the quantity of treated water and the precipitation-runoff-simulation. The patency value in this case is deduced from the settling effect and the filtration effect. For further information see DWA-M 153 ** these facilities are not usually applied for the rewuired amount of retention of solids *** German: Oberflächenbeschickung **** r_{crit} = critical rain yield factor, i. e. rainfall event the design is based on					

Tab. 28/b: Determination of the patency value of sedimentation and filtration facilities, according to the scoring system of the DWA-M 153 [KARLSRUHE REGIONAL COUNCIL, 2008]

Ideally, the required treatment facility should have a patency value (D) equal to the water resilience divided by the runoff load (G/B) or higher. By multiplying the patency value of the treatment system by the runoff load (D • B) the emission value (E) can be determined. The emission value (E) must be equal to the water resilience (G) or smaller.

In the following, a sample calculation is conducted [submittal by ROTH, 2008]:

Assumed is a highway section of 2,500 m length and a cross-section with an embankment width of 9 m, a trough width[106] of 3 m, a road surface width of 14.5 m and a median strip width of 3.5 m.

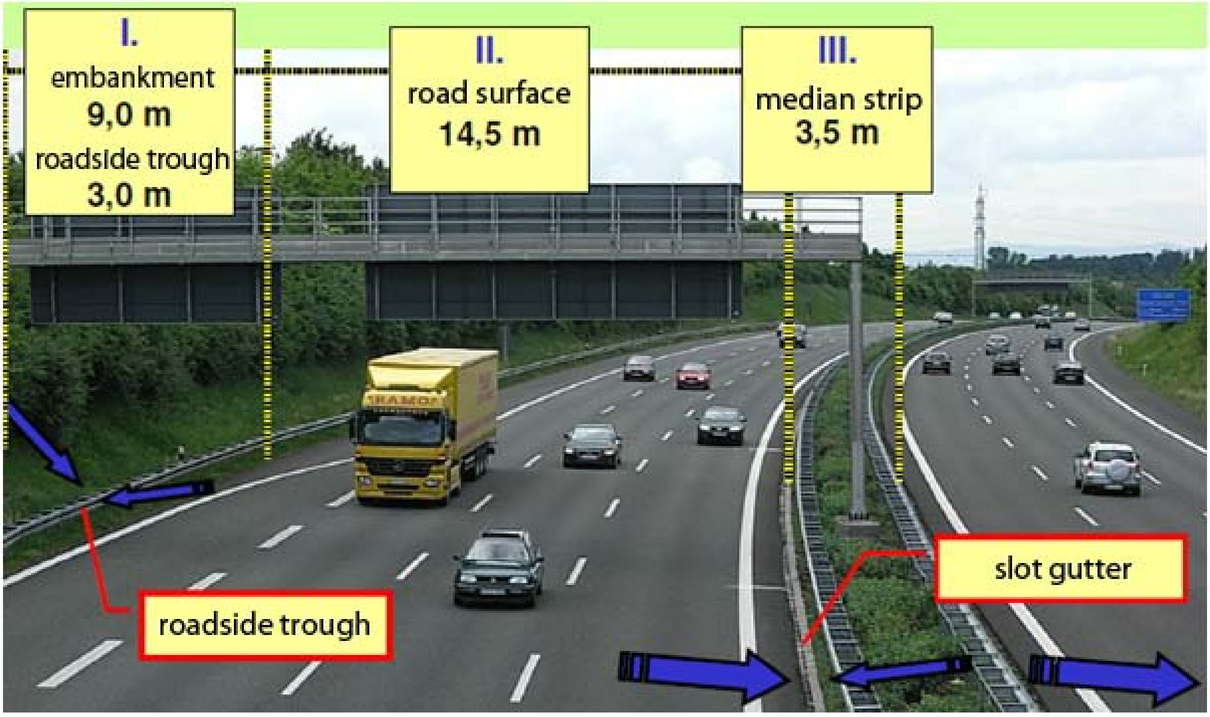

Fig. 21: Exemplary highway section for the sample calculation [submittal by Roth, 2008]

Step 1: Determination of the atmospheric preload (L) and the road pollution (F):

As seen above, the atmospheric preload outside urban areas is neglibile and thus scored with 1 point. The road pollution is calculated as follows.

→ L = 1

Embankment and trough surface:

A = length • width • ψ (run-off coefficient) • 10^{-4}
2,500 • (9.0 + 3.0) • 0.1 • 10^{-4}
approx. 0.3 ha

[106] assuming a deepened roadside greenery, as often found in practice

Road surface:

A = length • width • ψ (run-off coefficient) • 10^{-4}

2,500 • 14.5 • 0.9 • 10^{-4}

approx. 3.26 ha

Median strip:

A = length • width • ψ (run-off coefficient) • 10^{-4}

2,500 • 3.5 • 0.1 • 10^{-4}

approx. 0.09 ha

→ Total: 3.65 ha

→ Drainage over the roadside trough: 0.3 / 3.65 = approx. 0.08 (= 8 %)

→ Drainage from sealed surface in slot gutter: 92 %

According to table 25 the pollution of roads with a DTV exceeding 15,000 vehicles per 24 hours is categorized as F6 and scored with 35 points.

→ **F = 35**

Step 2: Determination of the water resilience:

The nearby receiving water of the exemplary site is a small hill stream and thus categorized as G5 (as seen in table 27/a) and scored with a resilience of 18 points.

→ **G = 18**

Step 3: Determination of the load (B)

B = $\sum$ fj (L + F) =

$$\underbrace{\{0.92 \cdot (1 + 35)\}}_{\textbf{slot gutter}} + \underbrace{\{0.08 \cdot (1 + 35)\}}_{\textbf{roadside trough}}$$

→ **B** = 33.12 + 2.88 **= 36**

Step 4: Comparison of load to water resilience

G = 18, B = 36 → **B > G** → treatment necessary

Step 5: Determination of the required patency value of the treatment facility

$D \geq G / B$

G / B = 18 / 36 **= 0.5**

Since the patency value must be 0.5 or higher, the category D24, design type a (as seen in table 28/b) applies. The treatment facility needs to be a facility (f. e. stormwater sedimentation tank) with permanent storage or permanent flow and a maximum of 7.5 m/h surface feeding by rcrit = 15 L/(s• ha). The annual average retention of solids should be 50 %, thus, design type a.

→ **D = 0.5**

→ Chosen facility score: 0.58

Step 6: Determination of the emission value and comparison to the water resilience.

$E = B \cdot D$

$36 \cdot 0.5$

→ **E = 18**

Step 7: Comparison of the emission value and the water resilience

E ≤ G

18 = 18

→ The facility type (just) fulfills the requirements. Design plans can be made.

4.2 Advantages and disadvantages

The main advantage of the scoring system is that it gives planners of road runoff treatment facilities the ability to handle designing and emission control consistently despite the heterogeneous external conditions, since the system regards the various sources of pollution (area loads and atmospheric preloads) as well as the vulnerability of receiving waters and thus forms the possibility to standardize these complex environmental conditions.

On the other hand, this particular standardization might bear the risk for planners to rely on the validity of the scoring system too much. This applies rather in urban areas, where the determination of the atmospheric preload and the general preload of pollution in the receiving waters are much more complex to determine. However, even in the assessment of the area load on highways and roads outside urban areas friction might occur. The area preload is determined by the DTV, which is a relatively reliable parameter. Yet, the advent of pollutants can be different along the line of a highly frequented road. Pollutants increase in turns and at gradients or slopes, where brake abrasions (and thus concentrations of f. e. zinc or copper) increase [ROTH, 2008]. In general, planners must keep in mind that the selection method according to DWA-M 153 is a decision aid and does not work as a replacement for the professional assessment that is required for the approval procedure. [KARLSRUHE REGIONAL COUNCIL, 2008]

Another disadvantage could be that this method does not regard economic factors like costs for acquisition, building and maintenance or the durability of a treatment facility, which are as important for some stakeholders in stormawater management on highways (f. e. the federal state governments or municipal awarding authorities in charge of the runoff treatment facilities) as the meeting of environmental standards and limit values.

Nevertheless, the method according to DWA-M 153 is a rather comprehensive method to handle the selection procedure and find an appropriate and sustainable treatment system or facility.

4.3 Transferability to the remaining federals states

From the stormwater management on highways as practiced in Baden-Wurttemberg it can clearly be seen that the selection method of appropriate treatment facilities for road runoff according to DWA-M 153 is well-transferable to other federal states. It is likely that many highway runoff treatment facilities throughout the Federal Republic of Germany are planned and designed with regards to this advisory leaflet, although surveying various ministries for road construction or environment did not clarity in this case.

5. Evaluation of treatment facilities

In 2010, the professional association DWA and the “German Federal Foundation for Environment”[107] (DBU) conducted a research project for the development of an inspection procedure (evaluation method) for facilities for the decentralized treatment of stormwater in the separate sewage system. It was developed as a rather comprehensive study, especially on urban stormwater management, which cannot be discussed in detail, since it would exceed the scope of this term paper by far. Nevertheless, it needs to be mentioned.

The research project promotes the amendment of the German Wastewater Ordinance (AbwVO), resp. the attachment of an annex that is dedicated specifically to the handling of contaminated stormwater, comprising federal uniform requirements for stormwater treatment, discharge and percolation. The decentralized treatment is of growing importance. Resulting from this finding, there is a significant potential for the application of industrial-built, standardized treatment systems/facilities, which aim on the efficient removal of individual pollutants. This generates a growing incentive to improve technology and increase the efficiency of the established and currently available treatment systems (also regarding the “retro-fitting aspect”).

Objective of the research project was the establishment of a standardized “constructive-regulatory” approval[108] for individual facility types, since periodical monitoring (resp. self-monitoring) of effluent concentrations or loads of actual operating stormwater treatment facilities is not likely to be viable (see also chapter 6 of this term paper). The testing of facility types was thus not conducted in practice (actual operation), but in laboratory experiments, since standardization requires the reliability and reproducibility of test results and is thus easier achievable under artificial environmental conditions. During the “constructive-regulatory” approval process, the specific requirements to the construction, operation and maintenance of the facility for proper functioning and operability must be set. This is best

[107] Deutsche Bundesstiftung Umwelt

[108] bauaufsichtliche Zulassung

accomplished by the standardized evaluation methods, resp. the necessary inspection processes that are developed in the research project.

The different work stages are the

- conception of an inspection procedure (evaluation methods must be quantifiable) with regards to different processes of functioning (f. e. removal processes)
- selection of relevant and expressive test parameters with regard to the relevance of the advent of individual pollutants[109], the relevance of the impact the individual pollutant has and practical aspects of laboratory tests (the test parameters must be individually set for every federal state)
- determination of representative load spectra for the charging of test facilities (by estimation and assessment of research and field monitoring data as well as practical experience)
- determination of objective values and general requirements for the inspection procedure (in laboratory)
- categorization of facility types according to their operating principle and size (i. e. space requirement, which often defines the applicability)
- development of requirements and further recommendations for planning/design, system structure and arrangement, operation and maintenance and quality management.

Inspection procedures (for the application in laboratories) for the standardized “constructive-regulatory” approval procedure were successfully developed by the research project. Exemplary elaborations were made for 8 different constellation of origin (f. e. roof areas, mixed areas, traffic areas) and destination (f. e. receiving waters, groundwater) of surface runoff as operating instructions for the testing laboratories.

Facilities for the research project were selected according to market analysis and regard currently applied treatment processes (f. e. sedimentation, adsorption,

[109] Relevanz des Aufkommens

filtration, light liquid separation). Tested were 3 facility types of different manufacturers for the decentralized treatment of heavily polluted surface runoff. Each facility type is sold in different variations:

- “3P Technik hydrosystem”, a combined system of sedimentation, adsorption and filtration in shafts with a diameter of 0.4 m or 1.0 m
- “REHAU RAUSIKKO sedimentation”, a combined system of sedimentation (type M) and additional light liquid separator (type R), in DN 1000 pipes with a length of 3 m or 9 m (variations M3, M9, R3, R9)
- “Fränkische Rohrwerke sedi-pipe / sedi-substrator“, a pipe sedimentation system in the variations 400/6 (DN 400, 6 m length), 400/12 (DN 400, 12 m length), 600/12 (DN 600, 12 m length) and 400/6+ (DN 400, 6 m length and additional substrate filter cartridge)

Selected effluent parameters for the test were TSS/VSS, COD (and BOD_5), TOC (DOC), MOTH, nitrogen compounds, phosphorus compounds, heavy metals (Zn, Cu, Cd, Pb), PAH (and benzo(a)pyrene as key component) and chloride.

notional origin of surface runoff	**TSS [mg/L]**	**VSS [mg/L]**	**TOC [mg/L]**	**COD [mg/L]**	**P_{tot} [mg/L]**	**Cu [µg/L]**	**Zn [µg/L]**	**Cd [µg/L]**	**PAH [µg/L]**	**MOTH [mg/L]**
roof areas	50	50	15	50	0.2	100	600	0.8	1.0	0.7
metal roof areas	50	50	15	50	0.2	3,000	6,000	0.8	1.0	0,7
traffic areas	200	100	20	100	0.5	80	440	5.0	2.5	1.0
mixed areas	150	80	20	100	0.8	80	500	2.5	2.0	1.0

Tab. 29: Assortment of relevant (influent) test parameters (selected by relevance of occurance) [DWA and DBU, 2010]

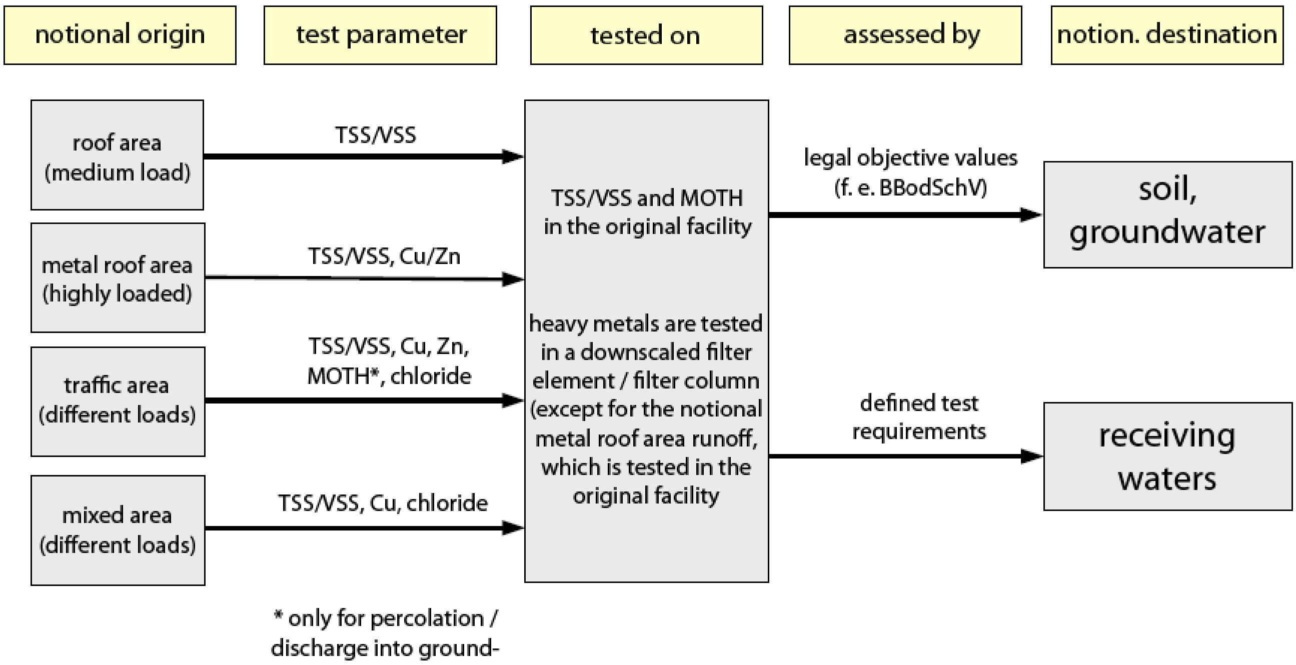

Fig. 22: inspection procedure for decentralized stormwater treatment in laboratory [DWA and DBU, 2010]

Conclusions were made on advanced operating, ideal settings, f. e. flow, rain yield factors (fed with 6 L/s•ha and 25 L/s•ha), sampling times (etc.) as well as transfer-, removal- and remobilization rates. Detailed information is geven by the DWA or [DWA and DBU, 2010].

6. Monitoring

'Monitoring' is an "umbrella term for all types of observation of intersubjectively perceptible system states over time" [PFEFFERMANN, 2011]. According to SPELLBERG (2005) 'ecological monitoring' means the "systematic measurement of variables and processes over time" provided that there is a "specific reason for that collection of data, such as ensuring that the standards are being met." This regards emission as well as immission values, depending on the monitoring approach.

In the context of this term paper 'monitoring of road runoff treatment facilities' means the controlling of functioning and operability of treatment facilities and systematic observation of certain parameters, regarding the runoff of these treatment facilities before discharging in the receiving waters or percolating through the soil. Thus, it is used as an emission-oriented term and does not regard the observation of immission values in the surrounding soil or water bodies.

6.1 Self-monitoring ordinances of the German federal states and the state of their implementation

The Federal Water Act and the state-own water acts of the federal states comprise clauses regulating the self-monitoring of wastewater treatment facilities. In most cases the federal state government is authorized to adopt an ordinance, which specifies the scope and requirements of self-monitoring. Many states have exercised this right. Yet, the extent to which regulations are made varies between the states. Annex 3 of this term paper provides a tabular representation of all self-monitoring ordinances or comparable arrangements. In this section the essential contents and similarities between the different ordinances are summarized.

Self-monitoring is to be conducted by the operator, resp. the agency in charge of highway maintenance[110] (AM), or by an authorized entity (i. e. service companies) on the expense of the operator. Most self-monitoring ordinances generally refer to all

[110] Autobahnmeisterei

common wastewater treatment facilities. This includes regulations for large municipal sewage plants as well as stormwater treatment facilities, which are rarely named explicitly. On this account, stated parameters that are to be tested mostly relate rather to domestic wastewater treatment or (if stormwater is concerned) relief structures like stormwater overflow basins in the combined sewage systems, for example nitrogen compounds, BOD_5 or COD. However, most self-monitoring ordinances envisage that parameters are determined by the local water authority in individual case decisions. Usually, results of the conducted self-monitoring are recorded and filed for a certain amount of time (the duration is mostly determined in the ordinances) and presented to the water authority in charge, if requested.

The local water authorities play a major role in the implementation of the self-monitoring ordinances relating to stormwater management on highways. Within the area of responsibility of water authorities on regional level falls the controlling and safeguarding of monitoring for many different wastewater treatment facilities. It is most likely that due to the financial as well as human resources shortage the controlling of self-monitoring of wastewater treatment facilities by the water authorities is mostly limited to the treatment of domestic wastewater as well as facilities of the combined sewage system, since common pollutants (f. e. nitrogen compounds, BOD_5, COD) in highest concentrations are rather found here than in stormwater treatment facilities of the separate sewage system. As a result of the survey that was conducted among several agencies in charge of highway maintenance (see also section 6.2.1 below) it can be assumed that the advent of pollutants in highway runoff is slightly underestimated in some cases, respectively it seems like the assumption that treatment facilities, which apply the current state of the art, safeguard the retention and removal of all relevant pollutants as long as they are operable properly, is relied on too much. However, the hazardous potential of road runoff is recognized by water authorities as well as at the executable level. The key point of the matter seems to be the financial aspect (indicated by various answers to the questionnaire). The conduction of special highway runoff treatment monitoring (in spite of missing demands by the mostly understaffed water authorities) would mean the autonomous, voluntary determination of parameters, measuring intervals and appropriate methods by the operator (i. e. the agencies in charge of highway maintenance) in consultation with the water authority. As long as there are no funds and workforce resources for demanding and controlling the implementation of the self-monitoring directives in reference to highway runoff treatment, the agencies in charge of highway maintenance are unlikely to apply expensive measuring instruments and cost-intensive conductions of self-monitoring on their own accord, since there actually is no legal obligation in most self-monitoring directives that specifically regard highway runoff quality measurements.

Research Society for Road and Transportation (FGSV) has released “suggestions for the controlling and maintenance of drainage facilities of non-local roads”[111] (H KWES, 2011) that should be applied if the individual federal state has not adopted a self-monitoring ordinance or no requirements are made for road runoff treatment facilities (by the self-monitoring ordinance or the local water authority). The H KWES is mainly concerned with operational aspects that ensure the long term efficiency of the facility and prevent harmful effects on the environment. Inspection of the hydraulic permeability of the road drainage and the operability and proper functioning of the treatment facilities should mostly be conducted visually.

[111] Hinweise zur Kontrolle und Wartung von Entwässerungseinrichtungen an Außerortsstraßen

Facility type / treatment system	Controlling	Interval	Suggestions
Facilities for sedimentation - sedimentation tanks - sedimentation tanks with lamella separators - sedimentation tanks with light liquid separators - rain purification basins	Visual inspection Proper functioning	Every 3 month	Check of inflow, overflow and outflow of the basins on deposits/sediments, water level and damage to the building Check of proper functioning by activation (if possible) to detect blockades Additionaly: Annual checks of the sediment layer thickness (emptying, if indicated) Annual inspection of trenches and ditches Controlling after heavy rainfall events
Facilities for hydraulic retention - detention basins - temporary storage channels	Visual inspection Proper functioning	Every 6 month	Check of inflow, overflow and outflow of the basins on deposits/sediments, water level and damage to the building Check of proper functioning by activation (if possible) to detect blockades Additionaly: Annual checks of the sediment layer thickness (emptying, if indicated) Annual inspection of trenches and ditches
Retention soil filters	Visual inspection Proper functioning	Every 3 month	Check of inflow, overflow and outflow of the retention soil filter on deposits/clogging, water level, inundation of percolation areas, damage to the building, undesired vegetation, root penetration and

			activity of animals Annual mowing / periodical removal of undesired vegetation (does not apply for reed or other plants to increase the efficiency) Check of proper functioning by activation (if possible) to detect blockades or clogging
Percolation systems above ground -percolation tanks - percolation troughs - ditches	Visual inspection	Every 3 month	Check of inflow and outflow of the retention soil filter on deposits/clogging, inundation of percolation areas, damages, undesired vegetation, root penetration and activity of animals At least annual mowing / periodical removal of vegetation
Percolation systems below ground	Visual inspection	Every 3 month	Sedimentation and control shafts of trenches and percolation shafts must be checked on deposits/sediments, water level and damage to the building

Tab. 30: Excerpt from the H KWES: controlling suggestions and intervals for the maintenance of road runoff treatment facilities [FGSV, 2011]

6.2 Highway runoff monitoring in the German federal states

As seen in the results of a survey conducted among several environmental or road construction authorities of the German federal states by PFEFFERMANN [2011], there is no centralized monitoring program in Germany. PFEFFERMANN gives some cross references to sporadic pollutant investigations and operating data of highway runoff treatment facilities that are presumably collected and recorded by the highway maintenance service (f. e. by keeping an operational log). This is the starting point of further investigation, as documented in the following passage.

6.2.1 Monitoring of road runoff treatment facilities by German agencies in charge of highway maintenance

Gathering information about the maintenance and monitoring of highway runoff treatment facilities in the German federals states, a survey among several agencies in charge of highway maintenance was conducted over the time from October 2011 to January 2012. The questionnaire, which was attached to the e-mails, was compiled in collaboration with Dipl.-Ing. Julia Rempp, thus it contains questions on monitoring as well as on nature-orientated practices in road runoff treatment. It is attached to this paper (annex 1).

The major part of the questioned agencies did not reply at all, and of those who did, most answered, that they did not have any monitoring system for their highway runoff treatment facilities, since the legal requirements for that are not clear-cut enough.

Nevertheless, some agencies in Hesse, Lower Saxony, Saarland and Northrhine-Westphalia claimed, that they had some sort of reduced monitoring, regarding the regular scheduled cleaning and maintenance of road runoff treatment facilities by the field service personnel that has to ensure the proper functioning of all treatment facilities. Pollutant loads and concentrations are checked in none of these cases, mostly “due to the high expenses” [KOLKS, 02/21/2012, survey] and the fact that” there is no legal obligation to conduct such investigations”. As seen in section 6.1 as well as annex 3 the Northrhine-Westphalian self-monitoring ordinance indeed refers only to maintenance of facility functioning and operability, not to water quality.

According to a written reply from KOLKS (02/21/2012, survey) from the authority for road construction of the federal state Northrhine-Westphalia[112] continual analysis of water quality before and after treatment in a highway runoff treatment facility is conducted only within the scope of research assignments. Yet, the implementation of water quality monitoring can in some cases be demanded in the requirements attached to a decision on official planning approval[113] by the responsible plan approval authority. These rather scarcely imposed requirements could be f. e. instructions on regularly scheduled (two to three times a year) analysis of runoff water after passing the highway runoff treatment facilities or measuring of the pollutant content at the bottom of absorbing wells or leaching basins. But in most cases, there are no such requirements. [KOLKS, 02/21/2012, survey]

6.2.2 Monitoring of road runoff treatment facilities by the AM Diedenbergen, Hesse

One of the surveyed agencies in charge of highway maintenance, the AM Diedenbergen, invited the MASH research group[114] to an interview combined with a site visit. Thus, the occasion arose to get insight into the practical implementation of European, federal and state-own law in the stormwater management of the agency in charge of highway maintenance in an urban agglomeration area. Diedenbergen is located near to Frankfurt am Main. Within the range of the AM Diedenbergen there are highly frequented sections of the two major highways A 3 and A 66 as well as the important airport of Frankfurt am Main.

In the area of responsibility of the AM Diedenbergen most of the highway runoff percolates directly over the embankments. But there are also some stormwater holding tanks (some with, some without downstream percolation tanks) with light liquid separators for oil or gasoline. These tanks require regular checks and

[112] Landesbetrieb für Straßenbau Nordrhein-Westfahlen

[113] Planfeststellungsbeschluss

[114] B.eng René Ceko, Dipl.-Ing. Julia Rempp, B.eng Kathrin Schmollinger

maintenance. Also, there are two facilities on the site of the AM Diedenbergen, with light liquid separators connected upstream before discharging into the receiving waters or percolating through the soil, that require periodic inspection: An in-house[115] gas station and a washing station for the service trucks. [BAMBACH, 11/29/2011, interview]

For these facilities there is no monitoring system [BAMBACH, 11/29/2011, interview], but in the course of the preventive maintenance, some sort of “mini-monitoring” can be accomplished. The proper functioning of the light liquid separators is thereby the primal thing inspected. Furthermore, the hydraulic permeability of the runoff treatment facility has to be ensured and possible clogging of the grit removal in the road gullies must be prevented.

Corresponding to a form for the keeping of an operational log (figure 23), which is based on the form sheets MVD-2 and MVD-3 released by the HLUG, the runoff treatment facilities on rural roads and highways, which were built according to RiStWag, as well as the facility applied to the washing station, built according to the Hessian administrative rule “Operation and maintenance of light liquid separators in accordance with the DIN 1999”, require a maintenance rate of six month. The German instruction for the building of gas station (TankVO), according to which the in-house gas station was built, does not specify the maintenance interval. Still the form instructs the AM Diedenbergen to check the light liquid separators twice a year. These regularly scheduled checks are conducted once a month for the separators of the runoff treatment facility according to DIN 1999 and every three month for the separators of the runoff treatment facilities according to RiStWag. The latter are also checked after every heavy rainfall. These indications by the AM Diedenbergen are confirmed by the AM Seesen in Lower Saxony, which gave a similar statement on the service intervals from their operational log. It is likely that most agencies in charge of highway maintenance have comparable maintenance intervals and operational logs, although they are not explicitly preset by every state-own self-monitoring ordinance.

[115] hier: betriebseigen

In the course of this "mini-monitoring" conducted by the AM Diedenbergen, the deposit layer thickness of the separated light liquids and the sludge in the mud trap are checked and, if necessary, emptied. Also, the automatic closing-off and the optional alarm transmitter are tested on correct operation. To detect a possible clogging of the coalescence separator, the water level (average flow[116]) before and after the coalescence insert is measured and the feed pipe is inspected cursorily. In addition to that, the coalescence material is reviewed in the course of the biannual maintenance. If necessary, the coalescence application must be replaced. The drain channel of the access shaft is cleaned out after carrying out every inspection.

As soon as the separated light liquids exceed 80 % of the storage capacity and/or the mud trap volume is only working to half capacity, the separator must be emptied. According to the data sheet, this is due every two years, but the experience seems to be different, since the interval of emptying has been graphically changed to five years for the facilities according to RiStWag and DIN 1999. If the facility does not seem to work properly or the feed pipe is suspected to be leaky, the inner coating and the built-in parts of the facility must be thoroughly inspected, where appropriate and necessary under the employment of cameras. When indicated, the buoyancy of the floater must be tested. If the highway drainage does not work properly and punctual strains and pollution are on hand, the road surface is usually purged with a high pressure cleaner [BAMBACH, 11/29/2011, interview].

[116] bei durchschnittlichem Durchfluss

10.06.96

Wartung und Entleerung von Leichtflüssigkeitsabscheidern nach:
Allgemeinverfügung "Hochbau" Nr. 1/96 411 St-62e-06-03/05 vom 18.03.96

	Waschplatz/Waschhalle Abscheider VwV (nach DIN 1995)	Eigenverbrauch-Tankstelle Tank VO	LFA an überörtl. Straßen Ri St Wag
Kontrolle	monatlich	halbjährlich	1/4 jährlich sowie bei Unfällen und Starkregen während Trockenperioden
Wartung	halbjährlich	----------	halbjährlich
Entleerung	Abstand 2 Jahre neu 5 J (14 Anl 23/00)	Abstand 2 Jahre	Abstand ~~2~~ 5 J Jahre
Überwachung	jährlich durch anerkannten Sachverständigen	nicht erforderlich	kann entfallen
Wasseruhr ablesen	wöchentlich	-----------	-------

Kontrolle:
a) Messung der Schichtdicke der abgeschiedenen Leichtflüssigkeit im Abscheider
b) Messung der Lage des Schlammspiegels im Schlammfang
c) Kontrolle der Funktionsfähigkeit des selbsttätigen Abschlusses im Abscheider und evtl. vorh. Alarmeinrichtungen
d) Messung des Wasserstandes vor und hinter dem Koaleszenzeinsatz bei Wasserdurchfluß, um eine Verstopfung des Einsatzes zu erkennen
e) Prüfen der zugehörigen Zuleitung auf Beschädigung

Wartung:
a) Überprüfung des Koaleszenzmaterials des Abscheiders, erforderlichenfalls Austausch oder Reinigung
b) Entleerung und Reinigung des Abscheiders soweit erforderlich (z.B. bei starker Verschlammung).
c) Reinigung der Ablaufrinne im Probenahmeschacht

Entleerung
-wenn die Menge der abgeschiedenen Leichtflüssigkeit 80% der Speichermenge erreicht hat.
-wenn die abgeschiedene Schlammenge die Hälfte des Schlammfanginhaltes erreicht hat.

zusätzliche Prüfung:
a) Sichtkontrolle des Zustandes der Innenbeschichtung und der Dichtheit sowie des Zustandes der Einbauteile
b) Prüfung der Schwimmertarierung.

Fig. 23: Form “Maintenance and emptying of light liquid separators”, AM Diedenbergen, scan of the German original submitted by [BAMBACH, 11/29/2011]

Pollutant loads and concentrations in the runoff water before and after the highway runoff treatment facility are not investigated [BAMBACH, 11/29/2011, interview]. Only in case of an exceptionally high pollution, for example caused by an accident, or if the pre-flooder, in which the treated runoff water is discharged, is proven to bear an unusual high level of contamination, the water authority in charge can order further monitoring of the concentration and load of noxious substances in the runoff water from the highway runoff treatment facility. According to the head operator [BAMBACH, 11/29/2011, interview], this has not even once been the case, since he works for the AM Diedenbergen.

The specifications of the form (fig. 23) have been applied since 1996 and were not changed [BAMBACH, 11/29/2011, interview], except for the conditioning of the emptying-intervals, as described previously. Even with the instauration of a certain section of federal highway A3 in the area of responsibility of the AM Diedenbergen, including the renewal of drainage lines and stormwater holding tanks, in this Winter of 2011/2012, the instructions are unlikely to change, since there will be no application of new technology. Only the dimensioning and design of the drainage system and the runoff treatment facilities are adjusted to the new conditions. Continuative monitoring of those instaurated wastewater treatment facilities is, given the fact that the legal guidelines will not change, not intended for the future. [HEISERHOLT, 11/28/2011, interview]

6.3 Possible decentralized monitoring programs

Since a centralized monitoring program applied for all highway runoff treatment facilities is not viable due to the high expenses and the human resources shortage in water authorities as well as agencies in charge of road maintenance, monitoring should be conducted individually. This decentralized monitoring does not mean the spot-checking of various random treatment facilities of different types, but the continual surveillance of one particular representative facility for a couple of years, which makes it possible to assess the functioning, the hydraulic as well as pollutant removal capacity and the operability (in practice) of the facility type. This could be conducted for several facility types, which can be compared in relation to their individual effectiveness, performance and costs afterwards.

One good example for facility type monitoring by reference to an individual highway runoff treatment facility is the monitoring of the "SABA Attinghausen"[117], a treatment facility for heavily loaded highway runoff in Uri canton, Switzerland [STEINER and GOOSSE, 2009]

A prediction of the applicability of established facilities for domestic or industrial wastewater treatment to highway runoff treatment, concerning pollutant removal performance, operational stability and costs of maintenance and disposal (of sediments and screenings), is difficult, since quantity and load of highway runoff are dynamic. The implementation of "new" treatment systems therefore requires "pilot facilities" that are monitored, before they become standardized treatment methods in the management of stormwater on highways in Switzerland.

According to the guidelines and regulations adopted by the Swiss federal authority for environment, forestry and landscape[118] (BUWAL) highly polluted road runoff must be treated in (vegetated) retention soil filters. The disadvantage of this treatment method is the high space requirement; another issue is the relatively low hydraulic conductivity and thus a slower percolation performance. On account of the low land availability alongside many highways in Switzerland, the development of road runoff treatment facilities that require less space (resp. are able to treat a higher amount of runoff water per square meter than retention soil filters at the same or at least comparable efficiency) and are easily operable and maintainable was aspired by the Uri canton administration. The developed facility type, a two-stage treatment system that will be described in the following, was built and applied in three locations along the federal highway A 2 in Uri canton: Attinghausen, Wiler and Epp. The facility in Attinghausen was built in 2005, monitoring was conducted from December 2006 to

[117] SABA is the abbreviation for "Straßenabwasserbehandlungsanlage", which means road runoff treatment facility

[118] Schweizer Bundesamt für Umwelt, Wald und Landschaft

December 2008. Up to now, long term assessment has carried on the measurements applied during monitoring at larger intervals and will proceed until 2013.

The highway runoff treatment facility in Attinghausen consists of two essential stages. The first stage is a stormwater sedimentation tank with implied lamella separator (screens are not stated explicitly, but assumed to be upstream to the sedimentation tank). The second step is divided in two retention filter basins. The "Ferrosorp"-basin is a retention sand filter with layers of iron hydroxide coated filter sand, while the zeolite-basin consists of layers of zeolite coated filter sand. Treated water is discharged into the stream "Stille Reuss". The structure and arrangement of the different treatment stages can be seen in figure 24.

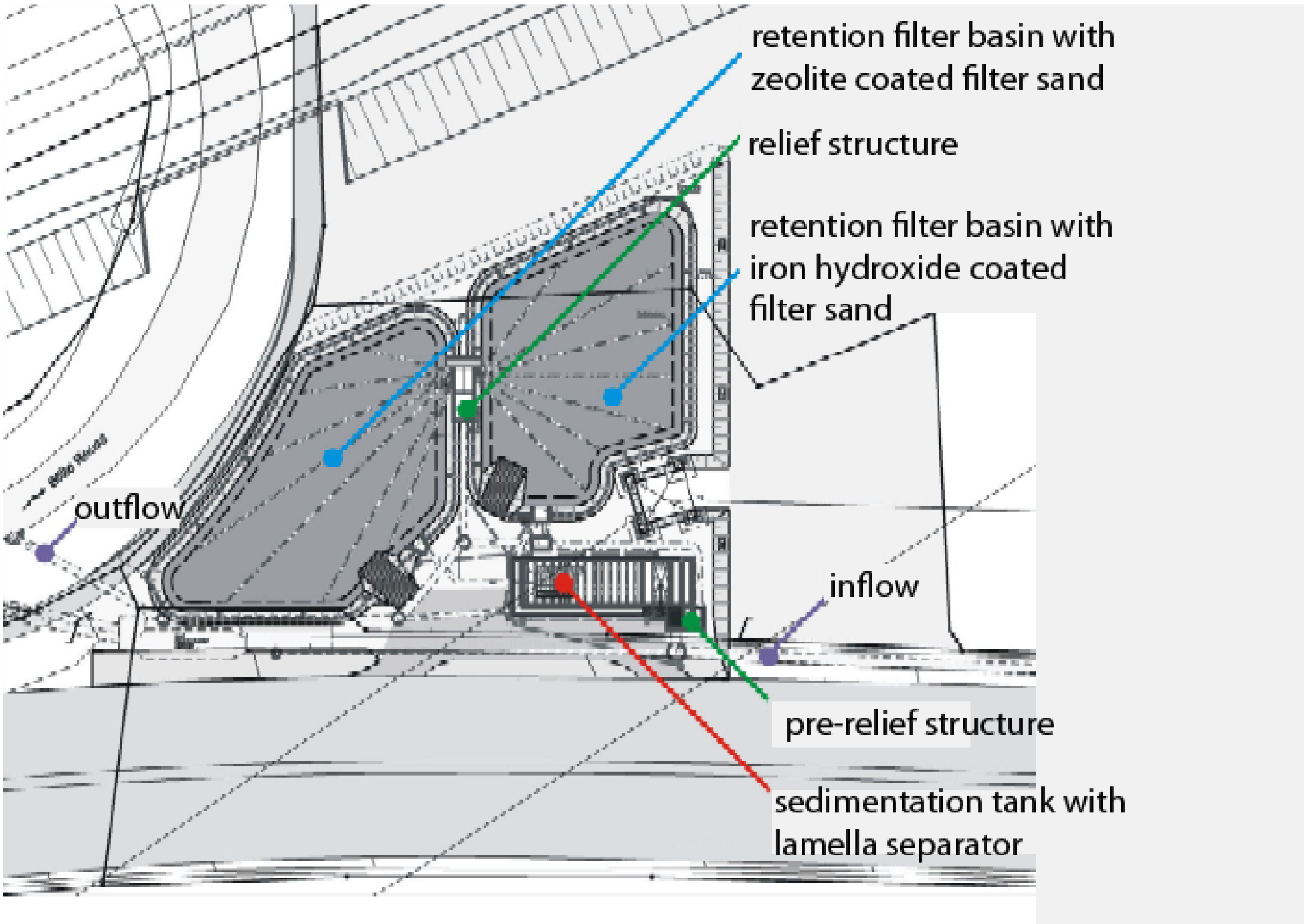

Fig. 24: arrangement of the treatment stages in the "SABA Attinghausen" [STEINER and GOOSSE, 2009]

Since deicing-salts that are used in winter affects the pollutant removal performance of the zeolite coating, the treatment facility has two operational "modes": summer operation (with Ferrosorp and zeolite filter basins applied) and winter operation (with only the Ferrosorp filter basin applied). During monitoring, however, summer operation was limited to the zeolite basin to assess the individual performances of the different adsorption filter types.

The facility requires 2,200 m^2, while the connected road area is 11.5 ha. The daily traffic volume of the A 2 is assumed with 20,000 to 30,000 motor vehicles per 24 hours.

Before the monitoring was conducted, objectives were set (as seen in table 31) and appropriate sampling locations and parameters were determined (as seen in figure 25).

Objectives	**Pre-release**	**Lamella separator**	**Ferrosorp RFB***	**Zeolite RFB***	**SABA (total)**
Examination of the hydraulic performance and capacity	x	x	x	x	(x)
Determination of clogging potential			x	x	
Determination of effluent concentrations and effectiveness		x	x	x	X
Applicability of operational concept		x	x	x	X
Determination of the expenses of operating and maintaining					X
Determination of costs and expenses of disposal (sugde/sediments, screenings)					X
Generalization and standardization of the results for the transfer to facilities of the same type		x	x	x	X
* RFB = retention filter basin					

Tab. 31: Objectives and open questions preset to the monitoring program, allocated to the different stages of the treatment system [Steiner and Goosse, 2009]

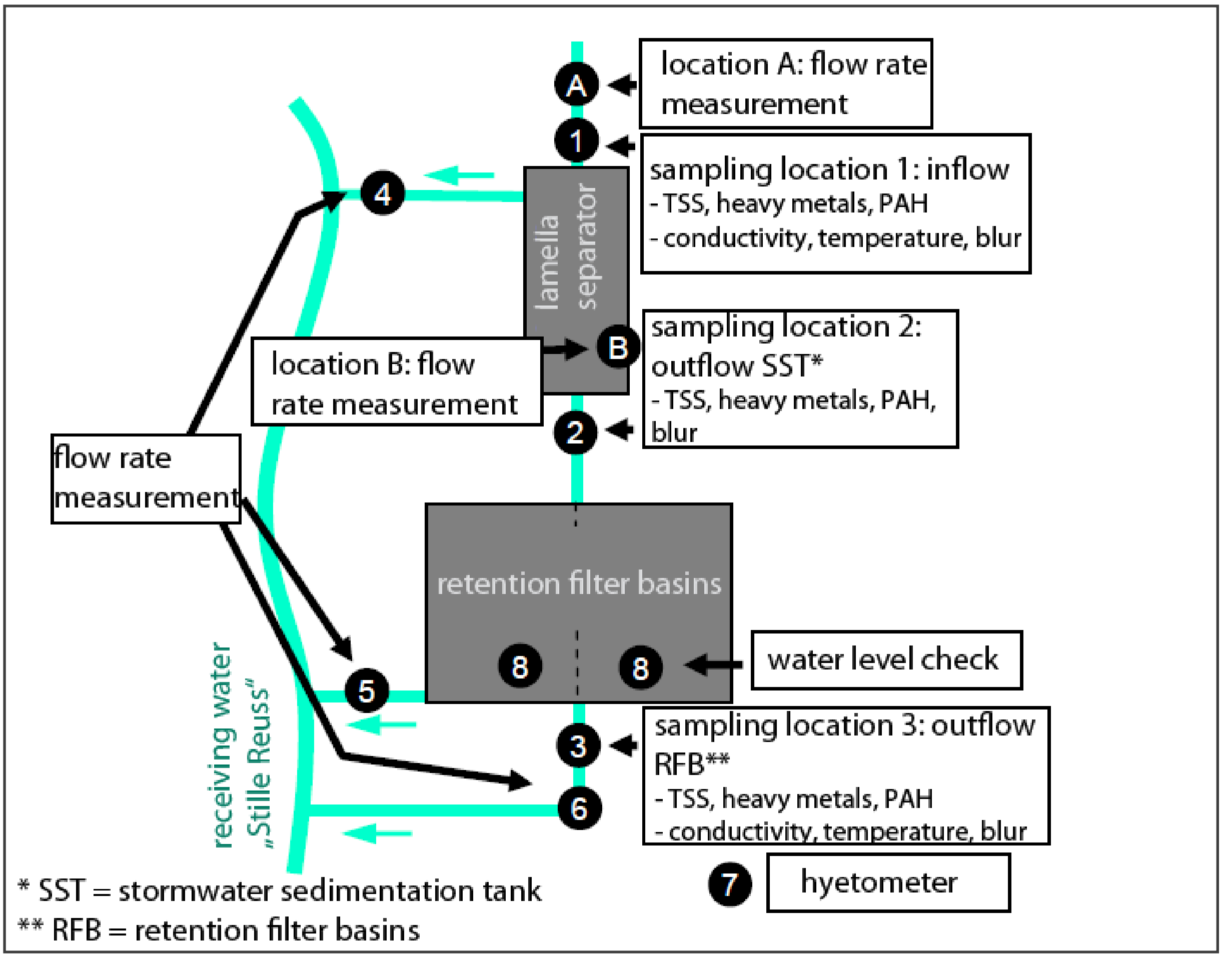

Fig. 25: Schematic arrangement of measuring points and sampling locations [STEINER and GOOSSE, 2009]

The location A for flow rate measurement was changed in march 2008 to location B due to the blockade of the testing probe and the distortion of measuring results arising from high input of leaves and trimmings into the open feeding channel. Samples from locations 1 – 3 were taken automatically and kept in thermostatization until removal for the laboratory analysis. The sampling was conducted flow-proportional, which means samples were taken every 40 m^3 until June 2008 and every 60 m^3 afterwards (flow rate measurement), resp. every 40 m^3 until June 2008 and every 100 m^3 afterwards (outflow retention filter basins). This approach made it possible to take samples during entire storm events and to determine hydrographic information about runoff dynamics (resp. inflow-outflow dynamics etc., detailed information is provided by [STEINER and GOOSSE, 2009]). Measuring point 7, the hyetometer, collected and measured precipitation (height, intensity, duration) close to the treatment facility.

The assessment of the hydraulic capacity of the treatment facility revealed that 1.2 % of the total passage flow was discharged completely untreated over the pre-relief structure (see also fig 24) and 6.5 % was discharged over the relief structure before the retention filter basins (treated only by sedimentation). This means that 92.3 % of the total passage flow was completely treated. Most reliefs took part during the summer month, which indicates that reliefs between the sedimentation tank and the retention filter basins will decrease when the summer operation mode is applied as envisaged (with simultaneous operation of both retention filter basin types). However, the temporary decommissioning of the retention filter basins showed that climatic and biological processes, which have a positive effect on the hydraulic permeability of the treatment facilities (resp. prevent clogging), occur during these time spans.

For the assessment of the pollutant removal performance of the sedimentation tank with lamella separator influent and effluent concentration values were compared (see also figure 26 and 27). This revealed efficiency factors of 14 % (copper) up to 53 % (TSS), depending on the sampling method (see also figure 28). This showed that the sedimentation tank (resp. lamella separator) is, as expected, not sufficient for meeting the environmental standards (without subsequent filtration). Yet, it is an effective and appropriate pre-treatment method for the removal of TSS and thus the prevention of filter clogging.

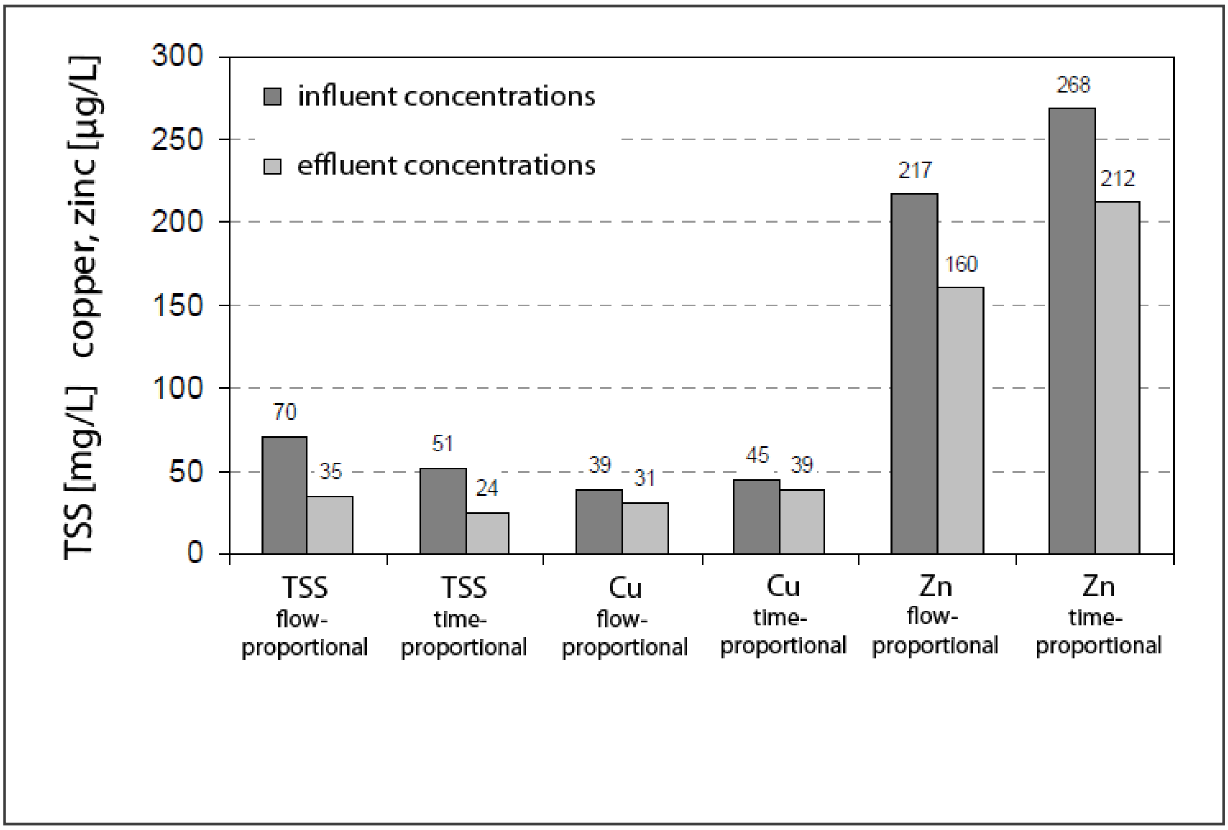

Fig. 26: in- and effluent concentrations (sedimentation tank / lamella separator) of suspended solids, copper and zinc, with flow-proportional as well as a time-proportional measurement [STEINER and GOOSSE, 2009]

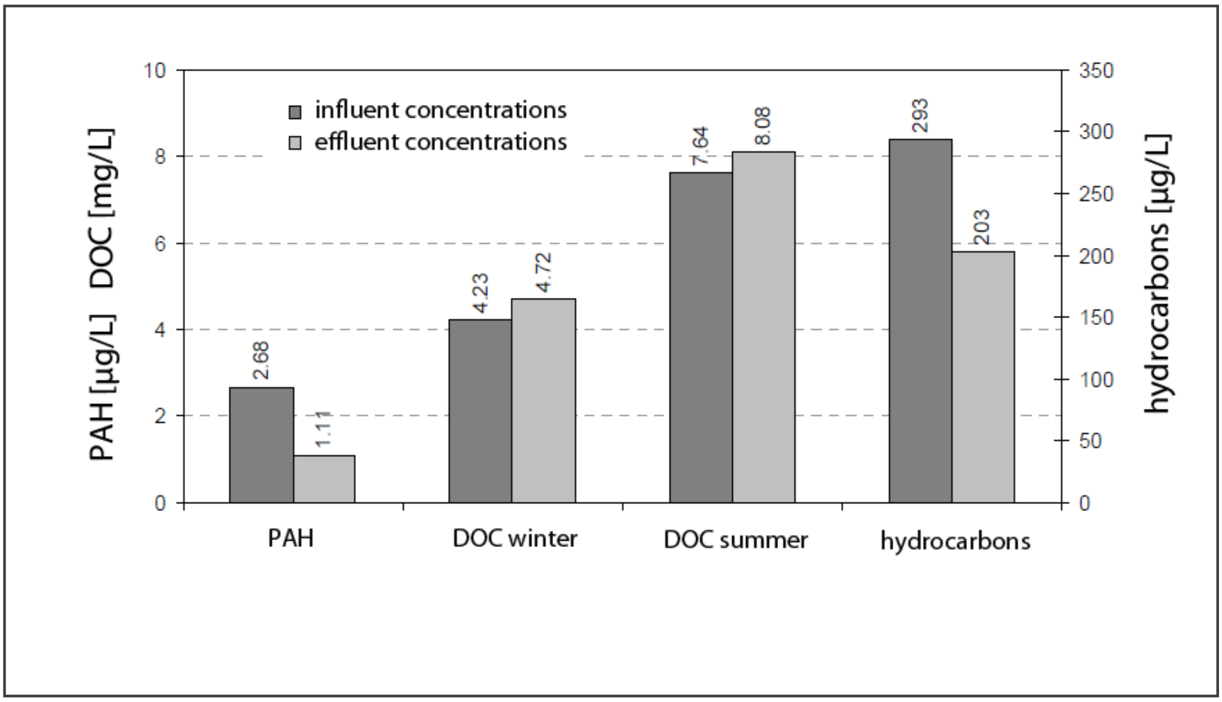

Fig. 27: in- and effluent concentrations (sedimentation tank / lamella separator) of PAH, dissolved organic carbon in winter and summer and hydrocarbons in general [STEINER and GOOSSE, 2009]

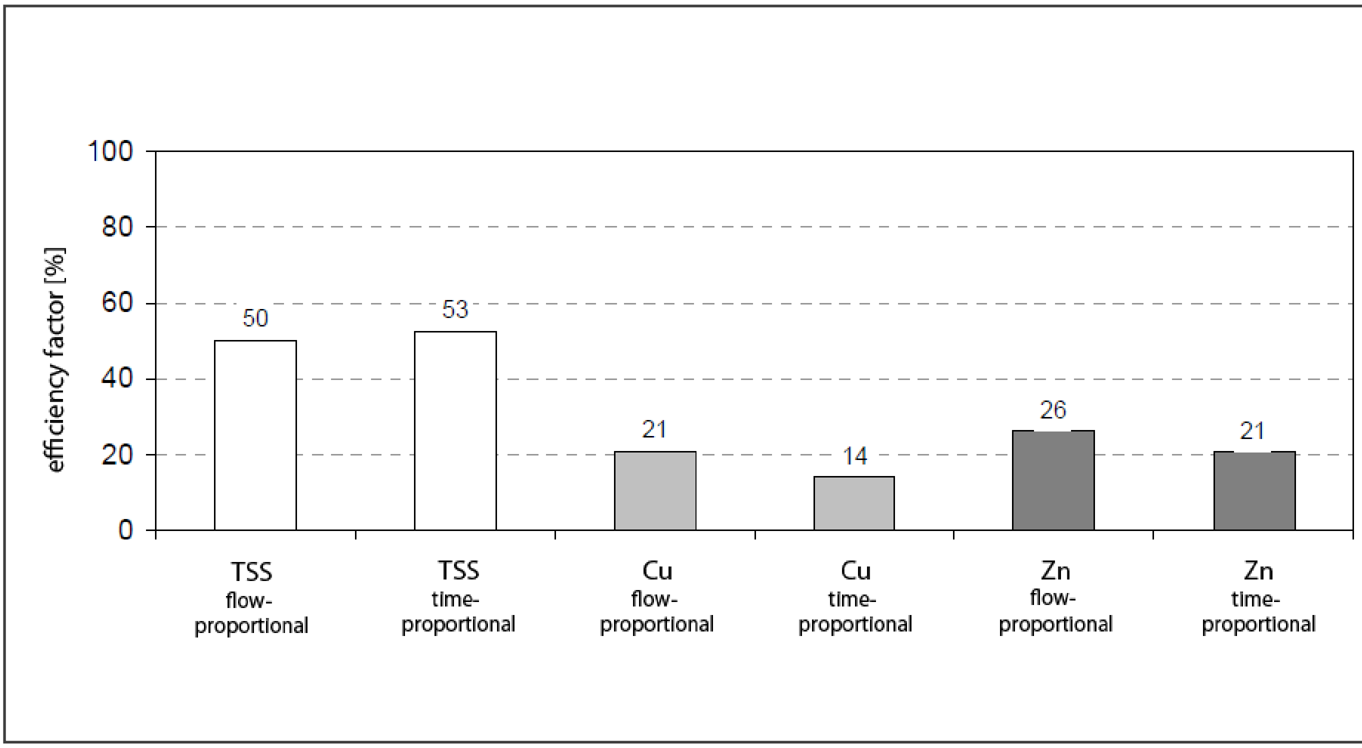

Fig. 28: efficiency factors (sedimentation tank / lamella separator) of suspended solids, copper and zinc, with flow-proportional as well as a time-proportional measurement [STEINER and GOOSSE, 2009]

The retention filter basins exhibit high efficiency factors for the removal of most pollutants. Solids are effectively held back in both filter systems, iron hydroxide coated as well as zeolite coated filter sand. The maximum permitted concentration for the discharge into receiving waters given by the Swiss water protection ordinance (last amended in 2011) of 20 mg/L was continuously met in every sampling. The median effluent concentrations (TSS) of the SABA Attinghausen of 3 – 8 mg/L (Ferrosorp) and 4 mg/L (zeolite filter) are below the limit value. Copper concentrations were strongly reduced in the retention filter basins as well. Median effluent concentrations of the SABA Attinghausen were ascertained at 6 – 10 µg/L (Ferrosorp) and 9 µg/L (zeolite filter) and thus lie far below the limit value of 0.5 mg/L. Zinc concentrations decreased even more significantly. Median influent concentrations (i. e. effluent concentrations of the sedimentation tank / lamella separator) of zinc were determined at 160 – 212 µg/L, whereas the median effluent concentrations were ascertained at 7 – 10 µg/L (Ferrosorp) and 13 µg/L (zeolite filter). Heavy metal concentrations (Cd, Cr, Ni, Pb, Mo, Sb, Fe) generally fulfilled the requirements.

Median effluent concentrations of dissolved organic carbon (DOC) were 2.4 mg/L (Ferrosorp) and 6.73 (zeolite filter). The limit value for the discharge into receiving waters of 10 mg/L is obviously met. The maximum permitted DOC concentration in groundwater[119] is at 2 mg/L and nearly achieved by the iron hydroxide filter system. Higher concentrations of DOC in the outflow of the zeolite filter basin are presumably on account of the input of organic material like leafs, trimmings or agricultural organic waste in the spring and summer month. Data of PAH concentrations were not stated for the zeolite filter basin. Median effluent concentrations of the Ferrosorp basin were 0.48 µg/L (for the sum parameter PAH) and 0.02 µg/L benzo(a)pyren as indicator substance. The median influent concentration of PAH was 1.11 µg/L.

Generally, it can be said that the objective to treat highway runoff as efficient as by a conventional retention soil filter, but with less space requirement, could so far be fully achieved. The sedimentation tank with integrated lamella separator performs well as

[119] immission-orientated value

a pre-treatment method for the retention filter basins, since they remove up to one half of the suspended solids and prevent filter clogging. The operating concept with two different filtration systems was accommodative to the monitoring, since it revealed different effects of performance in the two systems. Apart from the sound pollutant removal performance, the retention of hydraulic peaks and the throttling effect of the SABA Attinghausen were proven. Furthermore, the operating and maintaining expenses are low in relation to the performance and the excellent overall efficiency factor of the treatment facility. Maintenance basically consists in annual cleaning of the lamella separator and the removal of coarse material.

From the monitoring data various optimizations and recommendations could be deducted, f. e. on dimensioning, layer build-up of the retention filters, constructive details with regard to operability, operating concepts and future monitoring and measurement programs. The further development of the SABA Attinghausen is currently monitored by a long term monitoring project (until 2013). Open questions on the development of the pollutant removal potential and the hydraulic permeability with increasing pollutant load and the supposed lasting prevention of clogging due to inoperative phases will be investigated and shown in another monitoring report. Further information is provided by STEINER and GOOSSE (2009) and the Swiss company “Michele Steiner wst21”.

6.4 Conclusions on monitoring

A pollutant-related monitoring project is a good basis for the optimization of stormwater management on highways. Ideally, every treatment facility should be monitored and effluent concentrations should continuously be measured to assess the quality and efficiency of treatment in each individual case. This, however, is not viable due to the high expenses. A monitoring concept comparable to the Swiss monitoring project in Attinghausen, which means the monitoring of facility types in practice by using few representative treatment facilities, could be practicable in Germany as well. Monitoring in practice might even be more useful to the future management of stormwater on highways than the results of inspection procedure developments (as seen in chapter 5, see also DWA and DBU, 2011) for treatment facilities under “artificial” conditions. Approaches like the DWA and DBU research project (2011) are quite useful to assess the pollutant removal of facility types regarding maximum treatable concentrations or the operability and efficiency unter extreme hydraulic conditions. Yet, the actual composition of highway runoff in practice, the interactions between compounds and their quite unstable behaviour and properties in natural environment, the impact of different highway maintenance concepts and conditions as well as the impact of increasing/decreasing traffic intensity and unpredictable events cannot be covered and assessed (completely) in laboratory tests. The monitoring of actually operating facilities (“in practice”) can cover those aspects to a much greater extent.

7. Conclusions and look-out

The advent of pollutants in highway runoff and their impact on the environment as well as the connection to the traffic intensity was underestimated for a long time. Awareness arose mainly during the last decade, supposedly on the remarkable increase of road traffic. Many studies that address the topic of highway runoff pollution have been made[120] and a large number of legal regulations on water quality monitoring (emission- as well as immission-orientated) have been amended or newly adopted during the last decade. With the promotion of the separate sewage system and the objective to utilize and percolate stormwater whenever possible a crucial step towards sustainable stormwater management on highways and in urban areas was made. Generally, it can be said that the Federal Republic of Germany has implemented the European prescriptions, regulations and recommendations well into the German legal system (concerning general water management). Greatest achievements in emission control have so far been made in the centralized treatment of industrial and domestic wastewater. Industrial and wastewater treatment systems were improved continuously during the last two decades; emission values were reduced to a minimum, whereas the emission values of separate stormwater sewer outlets and treatment facilities were decreased to a lower extent. Thus, the improvement of stormwater treatment systems shows a large backlog demand. [MKULNV, 2011] Nevertheless, the currently applied facilities for the treatment of highway runoff (according to the state of the art) are, if functioning properly, mostly effective. However, there still are options and starting points for further optimization of highway runoff treatment[121]:

- Monitoring (see also section 6.4 of this term paper)
- Retro-fitting (subsequent installation of additional technical systems to improve the efficiency factor of treatment facilities and achieve the desirable upkeep with the state of the art)

[120] f. e. KOCHER and BEER (2007), DIERKES (no year), KREIN and SCHORER (2000) or SCHOLES et alii (2008), other see section 3.1 of this term paper

[121] based on personal impressions that were gained during the preparation of this term paper

- Improvement of communication and transfer of information on the management of stormwater on highways

Especially the last point seems to bear enormous potential for a nationwide improvement of stormwater management on highways. Most information about the individual handling of highway runoff management in the federal states was not easy to gather (resp. the data were partially confusing). In some states several ministries and authorities have addressed the topic of MASH and individually adopted guidelines, recommendations and leaflets (as did the professional associations and other institutions), but the executive level (f. e. the agencies in charge of highway maintenance) and the authorities seem to have a hard time keeping up, resp. seem to be overwhelmed with the implementation. Also, the financial and personal funds are short, as well on the executive level as on the supervisory bodies (i. e. the water authorities). Also, it appeared that many projects started by various ministries, governmental organizations and project groups (mostly depending on current subsidies and funding) targeting the improvement of stormwater management are not ultimately implementable or came to nothing at latest. An example is the Hessian digital sewage registry that was established to improve the work of the agencies in charge of highway maintenance, but is not effectively usable in practice, since it has not been extended beyond administrative boundaries; resp. has not been finished sufficiently [BAMBACH, 11/29/2011, interview]. Different systems, designed to simplify the management of stormwater on highways by different federal states (resp. differences within individual states, between different administrative units) seem to be not (or hardly) compatible with each other. Other starting points lie within the further investigation of the technical improvement or the substantial load of highway runoff and best management practices, which are also addressed in the project works of Dipl.-Ing. Julia Rempp[122] and B.eng. René Ceko[123].

[122] "Naturnahe Behandlung von Straßenabflüssen – "Best Practice"-Verfahren und Bedeutung der Vegetation", 2012

[123] master thesis on the physical-chemical treatment methods, best practice and the aspect of water protection areas, to be released in 2012

Sources

Legal regulations (laws, directives, guidelines)

2000/60/EC, European Water Framework Directive (Wasserrahmenrichtlinie), 2000

DWA-A 138, worksheet for planning, construction and operation of facilities for the percolation of precipitation water (Planung, Bau und Betrieb von Anlagen zur Versickerung von Niederschlagswasser), 2005

HmbAbwG, Hamburg Wastewater Act (Hamburgisches Abwassergesetz), 2001

RISTWAG, guidelines for structural measures on roads in water protection areas (Richtlinie für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten), 2002

TRENOG, technical regulations for harmless discharge of collectes stormwater into receiving waters (Technische Regeln zum schadlosen Einleiten von gesammeltem Niederschlagswasser in oberirdische Gewässer), 2009

UMBW, Decentralized Stormwater Abatement Regulation Baden-Wurttemberg (Verordnung des Umweltministeriums über die dezentrale Beseitigung von Niederschlagswasser Baden-Württemberg), 2007

WHG, German Federal Water Act (Wasserhaushaltsgesetz), 2009

References

ATV TASK FORCE, “Handlungsempfehlungen zum Umgang mit Regenwasser”, Arbeitsbericht, Korrespondenz Abwasser und Abfall, 43. Jahrgang, Ausgabe 8/96, 1996

DIERKES, “Decontaminating effects of soil-passages for the infiltration of road runoff”, University of Essen, undatiert (no year)

DWA and DBU, „Entwicklung von Prüfverfahren für Anlagen zur dezentralen Niederschlagswasserbehandlung im trennverfahren“, Abschlussbericht über ein Entwicklungsprojekt, 2010

ECKHARDT, HERMANN and MEYER, “Grundlagen der technischen Infrastruktur”, Skript zur gleichnamigen Vorlesung im Wintersemester, Studiengang UMSB, Hochschule RheinMain, 2010

ELLIS, DEUTSCH, MOUCHEL, SCHOLES and REVITT, „Multicriteria decision approaches to support sustainable drainage options for the treatment of highway and urban runoff”, Elsevier Science of the Total Environment, 2004

HERRERA environmental consultants, “Untreated highway runoff in Western Washington”, white paper for the Wahington State Department of Transportation, 2007

KOCHER and BEER, “Stoffeintrag in Straßenböden, Messzeitraum 2006/2007“ Berichte der Bundesanstalt für Straßenwesen (bast), Heft V 199, 2007

KOCHER, „Rückhalteleistung von Böden“, Vortrag zum Seminar „dezentrale Behandlung von Niederschlagswasser“ am 12. Mai 2011, nicht publiziert (unpublished)

KREIN and SCHORER, „Road runoff pollution by polycyclic aromatic hydrocarbons and ist contribution to river sediments“, University of Trier, 2000

KUMMER, Skript zur Vorlesung “Luftreinhaltung” im Wintersemester, Studiengang UMSB, Hochschule RheinMain, undatiert (no year)

MKULNV, „Dezentrale Niederschlagswasserbehandlung im Trennsystem – Umsetzung des Trennerlasses“, Nordrhein-Westfalen, 2011

PFEFFERMANN, “Management of stormwater on highways”, master thesis, Hochschule RheinMain, 2011

ROTH, “Bewertungsverfahren zur Auswahl der Behandlungsanlage für Straßenoberflächenabwasser“, Gemeinsame Informationsveranstaltung des Innenministeriums und des Umweltministeriums zu den Technischen Regeln Straßenoberflächenwasser bei der Landesstelle für Straßentechnik in Stuttgart, 3. / 10. Juli 2008, nicht publiziert (unpublished)

SCHOLES, REVITT, GASPERI and DONNER, “Priority pollutant behaviour in stormwater Best Management Practices”, Technical University of Denmark, 2008

STEINER and GOOSSE, „Monitoring SABA Attinghausen, Schlussbericht“, Zürich, 2009

SULZBACH MUNICIPAL WORKS, “Regenwassernutzung im Saarland”, undatiert (no year)

UHL and GROTEHUSMANN, “Handlungsempfehlungen zum Umgang mit Regenwasser – ATV-DVWK-Merkblatt M 153“, FH Münster, undatiert (no year)

UHL, „ESOG- Handbuch: Einleitung des von Straßen abfließenden Oberflächenwassers in Gewässer“, im Auftrag des MKULNV Nordrhein-Westfalen, 2006

WALZ and CEKO, “Menge, Eigenschaften und Behandlung von Straßenabflüssen in den deutschen Bundesländern“, interdisziplinäres Projekt, Hochschule RheinMain, 2011

WINKLER, “The characterization of highway runoff quality”, Diplomarbeit, Graz, 2005

Online-sources

BERLIN ENVIRONMENT, URL; 02/14/2012 http://www.berlin.de/umwelt/aufgaben/wasser-direkteinleitung.html

DAYWATER, URL; 02/23/2012 http://daywater.in2p3.fr/EN/guide/chapter1.php

DHS, URL; 02/03/2012 http://www.dhs.wisconsin.gov/eh/chemfs/fs/pah.htm

DIN, URL; 02/19/2012 http://www.din.de/cmd;jsessionid=F737FA48DB98A8B572D4D25AAFEC75D6.4?level=tpl-bereich&menuid=47421&cmsareaid=47421&languageid=de

DWD, URL; 02/03/2012 http://www.dwd.de/bvbw/generator/DWDWWW/Content/Presse/Pressekonferenzen/2011/PK__26__07__11/ZundF__PK__20110726,templateId=raw,property=publicationFile.pdf/ZundF_PK_20110726.pdf

EKVO Hesse, URL; 12/17/2011 http://www.rv.hessenrecht.hessen.de/jportal/portal/t/znq/page/bshesprod.psml?pid=Dokumentanzeige&showdoccase=1&js_peid=Trefferliste&documentnumber=20&numb

erofresults=1582&fromdoctodoc=yes&doc.id=jlr-EigenkontrollVHE2010rahmen%3Ajuris-lr00&doc.part=X&doc.price=0.0&doc.hl=1

FGSV A, URL; 02/19/2012 http://www.fgsv.de/

FGSV B, URL; 02/19/2012 http://www.fgsv.de/1437.html

HMUELV, URL; 01/10/2012 (download link) http://www2.hmuelv.hessen.de/umwelt/wasser/wrrl/oeffentlichkeitsbeteiligung/aktivitaeten/offenlegungbwpl/entwbwpl/

HMUELV, URL; 12/28/2011 (download link) http://www2.hmuelv.hessen.de/umwelt/wasser/wrrl/oeffentlichkeitsbeteiligung/aktivitaeten/offenlegungbwpl/entwmp//

HWAG, URL; 02/18/2012 http://www.umwelt-online.de/recht/wasser/laender/hh/lwg_ges.htm

HWAG, URL; 02/18/2012 http://www.umwelt-online.de/recht/wasser/laender/hh/lwg_ges.htm

KUHN, URL; 01/24/2012 http://www.dust-monitoring-equipment.com/images/papers/particle%20size%20diagram.gif

NAW DIN, URL; 02/19/2012 http://www.naw.din.de/cmd?artid=73720667&contextid=naw&bcrumblevel=1&subcommitteeid=54748262&level=tpl-art-detailansicht&committeeid=54739067&languageid=de

NLWKN, URL; 02/18/2012 http://www.nlwkn.niedersachsen.de/portal/live.php?navigation_id=8017&article_id=42498&_psmand=26

OEKOTEC, URL; 02/26/2012 http://www.oekotec-gmbh.com/de/bilder/inhalte/filter/ret_gr.jpg

OETZEL, URL; 02/15/2012 http://www.umweltanalytik.com/lexikon/ing1.htm#GlossTop

SAXONY, URL; 02/18/2012 http://www.umwelt-online.de/recht/wasser/laender/sachsen/nwfreiv.htm

SAXONY, URL; 02/18/2012 http://www.umwelt-online.de/recht/wasser/laender/sachsen/nwfreiv.htm

SEWAGETREATMENT.US, URL; 02/25/2012 http://sewagetreatment.us/wp-content/uploads/2010/11/Grit-chamber.jpg

SIEKER, URL; 02/19/2012 http://www.sieker.de/MKat/rechen_siebe_mischsystem.htm

SIEKER, URL; 02/23/2012 http://www.sieker.de/modules/tinycontent/index.php?id=2

SIEKER, URL; 02/24/2012 http://www.sieker.de/MKat/wirbelabscheider.htm

STATE GOVERNMENT SH, URL; 02/19/2012 http://shvv.juris.de/shvv/vvsh-7521.4-0001.htm

STATISTA, URL; 02/03/2012 http://de.statista.com/statistik/daten/studie/5573/umfrage/monatlicher-niederschlag-in-deutschland/

STEINHARDT, URL; 02/26/2012 http://steinhardtgmbh.com/the-efficiency-of-a-lamella-particle-separator/

UFT, URL 02/25/2012 http://www.uft-brombach.de/uploads/pics/0233-Wirbelabscheider.jpg

UNITRACC, URL, 02/26/2012 http://www.unitracc.de/aktuelles/artikel/optimierung-von-absetzbecken-zur-regenwasserbehandlung

WECLEANWATER, URL; 02/26/2012 http://wecleanwater.com/assets/images/success/manufacturing/brick-manufacturer-1312x868.jpg

WIKIPEDIA, URL; 02/03/2012 http://en.wikipedia.org/wiki/Heavy_metal_(chemistry)

WINNIPEG A, URL; 02/20/2012 http://www.winnipeg.ca/waterandwaste/images/sewage/combined.jpg

WINNIPEG B, URL; 02/20/2012 http://www.winnipeg.ca/waterandwaste/images/sewage/separate.jpg

Appendix

Annex 1: Questionaire (was sent to various authorities and agencies in charge of highway maintenance from October/November 2011 until January 2012)

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

Kurt-Schumacher-Ring 18, D-65197 Wiesbaden, www.hs-rm.de

Sehr geehrte Damen und Herren,

wir, zwei Studentinnen des Masterstudiengangs „Umweltmanagement und Stadtplanung in Ballungsräumen“ an der Hochschule RheinMain (Wiesbaden), arbeiten im Rahmen des europäischen MASH-Projekts („Management of Stormwater on Highways“) an einer Semesterarbeit. Dazu befassen wir uns unter anderem mit der Behandlung von mittel bis stark belasteten Straßenabflüssen..

Ziel der Arbeiten ist die Recherche von naturnahen Behandlungsverfahren, die sich in der Praxis bewährt haben (Best-Practice-Verfahren), sowie die Darstellung des Standes des Monitorings von Straßenabflüssen in den deutschen Bundesländern.

Bezüglich des Landes ____________ haben sich bei der Bearbeitung einige Fragen ergeben, die Sie uns möglicherweise beantworten könnten:

1. Existiert auf Ebene der Autobahnmeistereien ein Monitoringprogramm für Straßenabflüsse. Zum Beispiel bezüglich der eingesetzten Rückhalte und Behandlungseinrichtungen und/oder des Schadstoffaufkommens in Niederschlagwässern?
2. Werden im Zuge des Umweltmonitorings in der Umweltverträglichkeitsprüfung zum Planfeststellungsverfahren (oder sonstigen Genehmigungsverfahren für Straßenbauvorhaben) Maßnahmen zur Kontrolle des Ablaufwassers von Straßen durchgeführt?
3. Wird im Bereich der Autobahnen/Schnellstraßen, auch im Hinblick auf die Gefahrenabwehr bei der Freisetzung wassergefährdender Stoffe, ein Kanalkataster geführt, anhand dessen ersichtlich ist, wohin die Straßenabläufe geleitet werden? Gibt es Messungen zum Schadstoffaufkommen?
4. Welche naturnahen Verfahren zur Behandlung von Straßenabläufen werden eingesetzt? Gibt es Erfahrungen mit dem Einsatz von Retentionsbodenfiltern, Hydrobotanischen Teichen, Pflanzenkläranlagen und deren Kombination mit eher technischen Elementen (Regenrückhaltebecken), sowie Muldenversickerung über das Bankett? Welche Verfahren haben sich in der Praxis bewährt (Best-Practice-Verfahren)?
5. Warum bzw. nach welchen Entscheidungsparametern kommen diese Verfahren zum Einsatz?
6. Nach welchen Vorgaben wurden diese Anlagen geplant bzw. gebaut (DWA-ATV-Arbeitsblätter, sonstige Quellen/Vorgaben)?
7. Welche Vegetation und welches Filtersubstrat wurden/werden eingesetzt?

Wir würden uns freuen, von Ihnen zu hören (auch für den Fall, dass sie keine/wenige Fragen beantworten können), denn jede Information würde uns bei der Recherche erheblich weiterhelfen.

Vielen Dank im Voraus für Ihre Bemühungen!

Falls gewünscht, senden wir Ihnen nach Fertigstellung unserer jeweiligen Arbeiten gerne je eine digitale Ausfertigung.

Mit freundlichen Grüßen,

Kathrin Schmollinger / Julia Rempp

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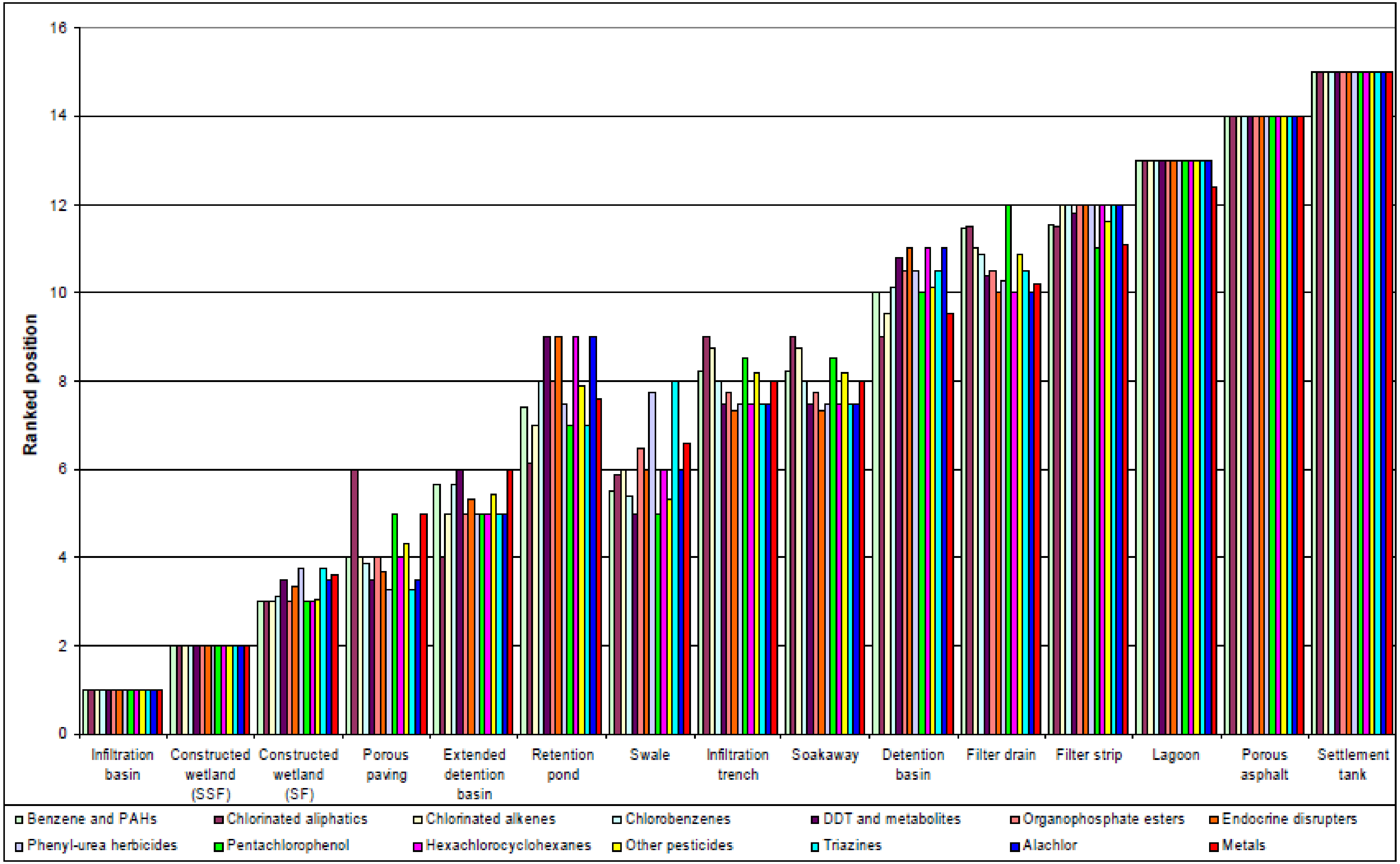
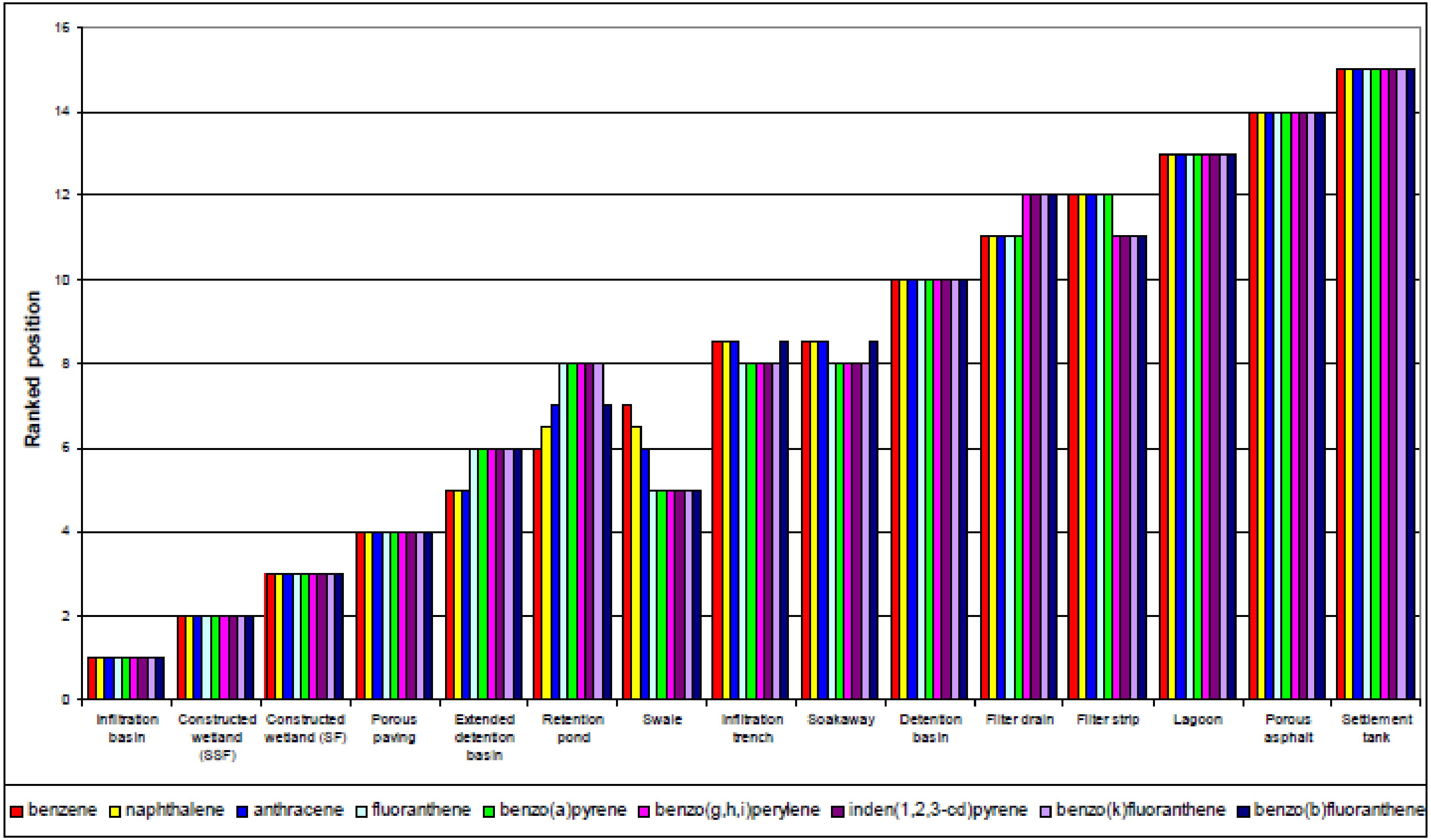
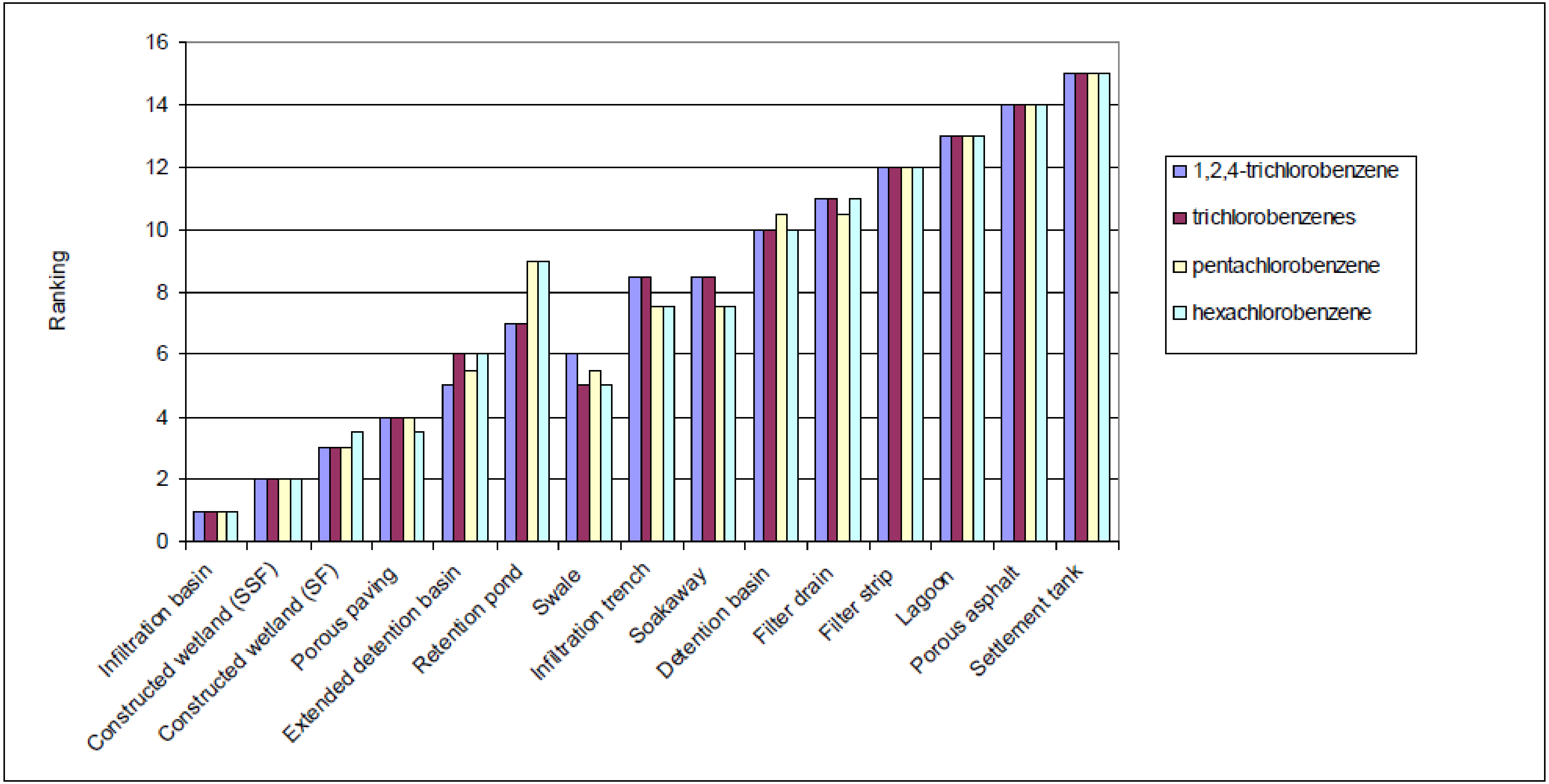
Annex 2: Ranking of best management practices for different pollutants (in addition to chapter 3 of this term paper)



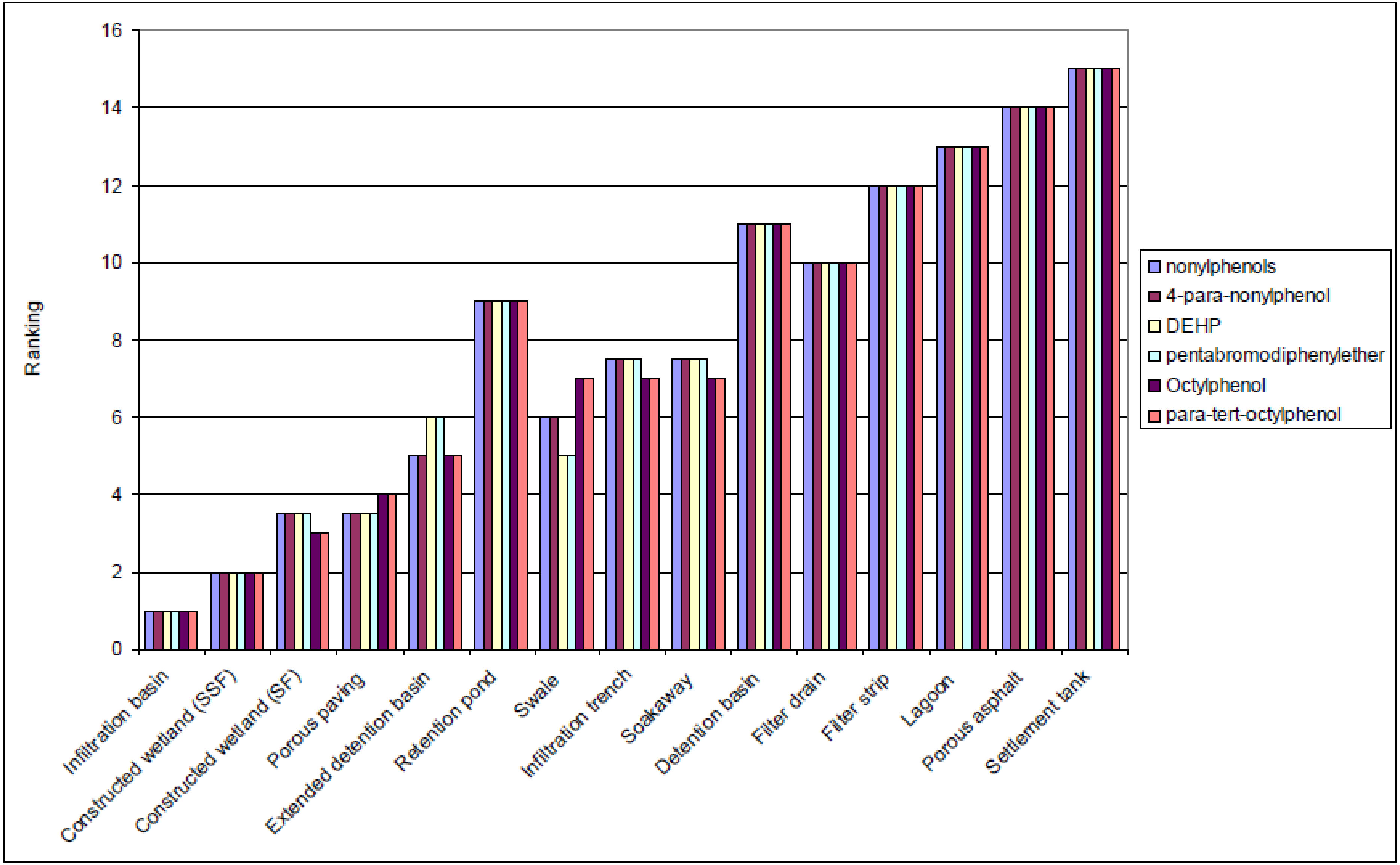
Overview of the best management practice order of preference for the removal of identified pollutants (selected by group) [SCHOLES et alii, 2008]



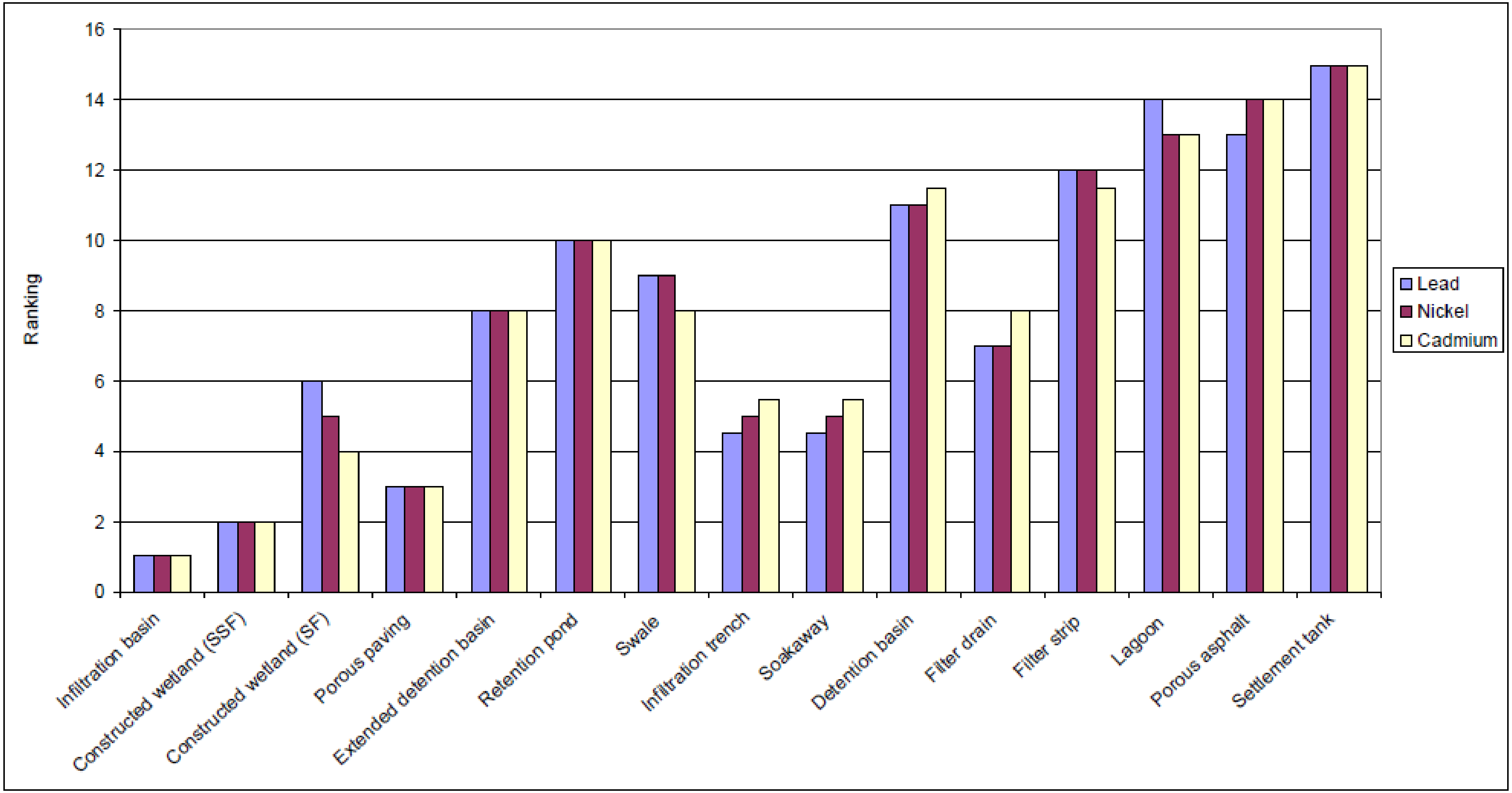
The best management practice order of preference for the removal of benzene and PAH [SCHOLES et alii, 2008]



The best management practice order of preference for the removal of chlorbenzenes [SCHOLES et alii, 2008]



The best management practice order of preference for the removal of nonylphenoles, octylphenoles and DEHP [SCHOLES et alii, 2008]



The best management practice order of preference for the removal of lead, nickel and cadmium [SCHOLES et alii, 2008]

Annex 3: Overview of ordinances in the federal states concerning the self-monitoring of wastewater treatment facilities by the operators in charge

Federal state	**Self-monitoring ordinance**	**Applies for highway runoff treatment?**	**Documentation of self-monitoring, data collection**	**Pollutants/ingredients that must be tested**
Baden-Wurttemberg	EKVO Baden-Wurttemberg, 2001	According to §1 EKVO Baden-Württemberg,	Operating documentation according to annex 1 and 2. The data must be presented to the technical authority in charge, if requested. Must be approved by the water protection officer („Gewässerschutzbeauftragter“) every 3 month	No specific pollutants/ingredients are stated. Tested should be visually („Sichtkontrollen“) for deposit, smell, color etc.
Bavaria	EÜV Bavaria, 1995	Not explicitly stated, but deductible from the context. (Applied to all wastewater treatment facilities)	Controlling of operation and function, measurements and tests according to annex 1 and 2. Data must be assessed, recorded and filed. If requested, the data must be presented to the authority in charge of water protection.	Ca, Mg, Na, K, Mn, Fe, Al, As, NH_4-H, Cl, SO_4, NO_3-N, NO_2-N, PO_4, SiO_2 (“Kieselsäure”), DOC (dissolved organic carbon) Ab-/adsorption coefficient, bacteria, color, blurring, smell, conductivity, pH-value, dissolved O_2, acid/base capacity, quantity
Berlin	No specific self-monitoring ordinance, § 29c BWG (water act) is applied	Not explicitly stated, but deductible from the context. (Applied to all wastewater treatment facilities)	§ 29c BWG: Operator of a wastewater treatment facility can be obliged to self-monitoring by the local district authority in charge.	No specific parameters are stated.
Brandenburg	No specific self-monitoring ordinance, §§ 73,	Not explicitly stated, but deductible from the context.	§ 73 WG Bbg.: Controlling by the water authority or an authorized entity at the expense of the operator can be requested. Records and data	No specific parameters are stated.

	75 WG Bbg (water act) are applied.	(Applied to all wastewater treatment facilities)	must be filed for at least 3 years. § 75 WG Bbg.: Generally, condition, operating and maintenance of road runoff treatment facilities is to be conducted by self-monitoring of the operator. Records and data must be filed for at least 10 years.	
Bremen	No specific self-monitoring ordinance, § 139 BremWG (water act) is applied.	Not explicitly stated, but deductible from the context. (Applied to all wastewater treatment facilities)	§ 139 BremWG: The water authority in charge can regulate self-monitoring by individual case decisions, specific to type and equipment of the treatment facility as well as the test intervals and the duration of requested collection and filing of data. Filed data must be presented to the water authority according to the individual requests and conditions.	To be tested is the “properties and quantity of the wastewater”. Pollutants/ingredients are determined in individual case decisions by the water authority.
Hamburg	No specific self-monitoring ordinance, § 17a HmbgAbwG (water act) is applied.	According to §1 Abs. 2 HmbgAbwG	§ 17a HmbgAbwG: The senate can determine the conditions, scope and requirements for authority approval of self-monitoring by adopting an ordinance (which has not happened yet).	To be tested is “the quantity and the physical/chemical and biological properties of the wastewater”. No pollutants/ingredients are specifically stated. The parameters to be tested must be determined in each individual case by the authority in charge.
Hesse	EKVO Hessen, 2010	According to §1 Abs. 2 EKVO Hesse	Requirements for self-monitoring and ducumentation by annex 2 (self-monitoring of stormwater retention tanks and overflows), form sheet MVD-2 released by the HLUG (Hessian Administration for environment and geology) Adittionaly, annex 3 (self-monitoring of facilities with direct discharge into receiving waters with	Annex 2: No pollutants/ingredients are specifically stated, hydraulic tests, condition and integrity of the facility is tested (“Bauzustandsprüfung”) Anhang 3: Determination of the measuring intervals according to the

			biological treatment applied, excluding constructed wetlands), form sheet MVD-3	size category of the facility. Quantity, BOD_5, COD, NH_4-N, total N, total P, compound-bound N in outflow.
Mecklenburg-West Pomerania	SÜVO Mecklenburg-West Pomerania, 2006	According to §1 SÜVO Mecklenburg-West Pomerania	Minimum scope of monitoring on condition and operating of facilities according to annex 2 According to §3 SÜVO Mecklenburg- West Pomerania the authorities in charge of road maintenance have to keep an electronic wastewater registry or (according to § 4) an operational log. The results should be recorded in an annual report by the operator.	NH_4-N, total N, total P, TOC, COD, Cl, Cr6 (“hexa-valant chromium”), cyanide, AOX, hydrocarbons, heavy metals pH-value, temperature, conductivity, quantity
Lower Saxony	No specific self-monitoring ordinance, § 100 NWG (water act) is applied.	Not explicitly stated, but deductible from the context. (Applied to all wastewater treatment facilities)	Data of self-monitoring must be collected, filed and presented to the water authority in charge, if requested. Operators of treatment facilities for non-domestic wastewater have to keep an electronic wastewater registry (it is not stated whether this applies for industrial wastewater treatment facilities only, or also for stormwater or road runoff treatment facilities)	No specific parameters are stated.
Northrhine-Westphalia	SüwV-Kan Northrhine-Westphalia, 1995	The SüwV-Kan is concerned with the operating and maintenance of the sewer system including relief structures and discharge facilities.	Water level must constantly be measured in rain overflow and rain purification basins as well as stormwater retention basins. Functioning and operability of facility equipment (f. e. throttles, measuring instruments, valves, pumps) are checked twice a year, facilities are also visually checked for clogging after heavy rain	No specific parameters are stated. There are no instructions for tests on pollutant loads in the self-monitoring ordinance.

			events. Basins are inspected every 5 years for damages to the structure (“Bauwerksschäden”)	
Rhineland-Palatinate	§ 57 LWG (water act) is applied	Rhineland-Palatinate has adopted an ordinance for the self-monitoring of wastewater treatment facilities (EÜVOA Rhineland-Palatinate, 1999), but according to § 1 stormwater treatment facilities are excluded.	According to § 57 LWG the water authority in charge can regulate self-monitoring by individual case decisions.	No specific parameters are stated.
Saarland	EKVO Saarland, 1994	Not explicitly stated, but deductible from the context. (Applied to all wastewater treatment facilities)	The EKVO Saarland distinguishes in facilities with biological treatment applied (annex 2) and exclusively chemical and physical treatment applied (annex 3)	NH_4-N, total N, total P, TSS, TOC, COD, Cl, Cr6 (“hexa-valant chromium”), cyanide, AOX, hydrocarbons, heavy metals pH-value, temperature, conductivity, quantity, O_2-content
Saxony	EigenkontrollVO Saxony, 1994	Not explicitly stated, but deductible from the context. (Applied to all wastewater treatment facilities)	The EigenkontrollVO of Saxony references the requirements of the Wastewater Directive and its annexes in § 2. Further paragraphs could not be consulted without purchase.	No data.
Saxony – Anhalt	EigÜVO Saxony-Anhalt, 2010	Not explicitly stated, but deductible from	Self-monitoring comprises the controlling of functioning and operability of the treatment facilities as well as their effectiveness, i. e.	No data. The annexes were not available without purchase.

		the context. (Applied to all wastewater treatment facilities, direct as well as indirect discharge)	examination of water (in/outflow) and its quality. The EigÜVO Saxony-Anhalt distinguishes in facilities with biological treatment applied (annex 1) and exclusively chemical and physical treatment applied (annex 2)	
Schleswig-Holstein	SüVO Schleswig-Holstein, 2007	Not explicitly stated, but deductible from the context. (Applied to all wastewater treatment facilities)	The controlling of self-monitoring of “direct dischargers” is an obligation of the regional water authorities. The operators (resp. agency in charge of maintenance) must perform self-monitoring or delegate is to service companies on their expense. To be controlled is the functioning and operability as well as the water quality. Methods of tests and analysis are individually determined by the water authorities. Data must be recorded and filed, ideally by keeping an operational log.	The given parameters refer rather to the treatment of domestic wastewater and large sewage plants: NH_4-N, total N, total P, BOD_5, COD, pH-value, temperature, conductivity, quantity, O_2-content
Thuringia	ThürAbwEKVO Thuringia, 2004	Not explicitly stated, but deductible from the context. (Applied to all wastewater treatment facilities)	To be controlled is the functioning and operability, water quality checks, the recording and filing of the resulting data (operational log). If these obligations are fulfilled by a third person, f. e. a service company, the water authority in charge must be informed about it. Annex 2 applies to rain overflow basins, rain purification basins and stormwater retention tanks (combined sewage system). Functioning and operability of facility equipment (f. e. throttles, measuring instruments, valves, pumps) should be checked.	No specific parameters are stated. There are no instructions for tests on pollutant loads in the self-monitoring ordinance.