Management of Stormwater on Highways

by

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Technical and Natural Based Treatment of Stormwater on Highways

Problem description:

The management of road surface runoffs is a common problem in developing and developed countries. New research results in various European regions show the relevance to the pollutant discharges caused by road runoff, the different kind of levels regarding the common law in this field and the difference in the applied treatment technologies. In this Masterthesis the situation in Germany, Switzerland and USA on the one side and the situation in Coratia on the other side has to be investigated and characterized. A description of the estimated developement in traffic infrastructure and esp. road networks in Croatia as well as a proposal of an developement plan for the legal situation and the technical application has to be done. Within the treatment processes both, natural and technical based treatment processes have to be considered.

Objectives:

- Literature- and internet-study considering recent research- and project-activities in Europe;
- Brief description of the different legal situations;
- Characterization of the common used technical and natural based treatment facilities in the above mentioned four countries;
- Description of the recent situation in Croatia and the future developement regarding the road networks/highways and the regional/urban planning;
- Proposal of an developement plan regarding

  -guidlines for the legal situation and

  -the technical and natural based treatment of road surface runoffs;
- Discussion of the results and proposal of further research needs.

Prof. Dr. Rudolf Eger Prof. Dr. Heinz Eckhardt

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CONTENTS

1. INTRODUCTION 1

1.1. Problem description 1

1.2. MASH project 3

1.3. Objectives 5

1.4. Layout 6

2. STORMWATER AND HIGHWAYS 8

2.1. Stormwater in general 8

2.2. Precipitation anlysis 13

2.3. Highways 21

2.3.1. Basic calculation method – „Rational method“ 23

2.3.2. Rational (runoff) coefficient 24

2.4. Hazardous substances (pollution) in stormwaters 27

2.4.1. Common pollutants and their sources 33

3. LEGISLATION 39

3.1. The law in the USA 40

3.2. The EU law 45

3.3. Law in the Federal Republic of Germany 48

3.4. Law in the Republic of Switzerland 52

3.5. Law in the Republic of Croatia 56

3.6. Summary 60

4. CROATIA AND ITS FUTURE DEVELOPMENT 62

4.1. Karst in Croatia 68

4.2. Transportation infrastructure and future development 72

4.3. Highways system in numbers 75

4.4. Sanitary protection zones 77

4.5. Current practices for stormwater management - criticism 83

5. STATE OF THE ART 85

5.1. Natural based treatment facilities 87

5.1.1. Vegetated Buffer Strips (Filter Strips) 88

5.1.2. Grassed Swale (Biofiltration Swale) 91

5.1.3. Extended Detention Ponds 94

5.1.4. Constructed Wetlands 98

5.1.5. Wet Pond 101

5.1.6. Infiltration Trenches 105

5.1.7. Infiltration Basins 108

5.1.8. Sand Filters 111

5.2. Technical based treatment facilities 115

5.2.1. Technical filtration 116

5.2.1.1. Fine Filters 119

5.2.2. Oil/Grit Separators 122

5.2.3. Sedimentation 125

5.2.3.1. Stormwater Sedimentation Tanks 127

5.2.3.2. Lamella Separators 131

5.2.3.3. Vortex Separator 135

5.3. Systems Performances 138

6. EVALUATION SYSTEM AND PROPOSAL OF DEVELOPMENT PLAN FOR CROATIA 147

6.1. Evaluation system of stormwater treatment facilities 148

6.2. Recommendations for future development of Croatia 162

6.2.1. Sources in fine grained porosity soils and from reservoirs and lakes and open watercourses 163

6.2.2. Sources in cracking and cracking-cavernous porosity soils (karst areas) 165

6.2.3. Monitoring 168

7. CONCLUSION (discussion of the results and future research) 169

8. SOURCES 172

List of Figures

Figure 1	Graphic display of hydrologic cycle [[2]; 31.03.2012.]	9
Figure 2	Infiltration of stormwater in undisturbed soil	11
Figure 3	Limited infiltration because of impervious cover	12
Figure 4	Forms of precipitation [[3]; 31.03.2012.]	14
Figure 5	Precipitation map of USA [[4]; 02.04.2012.]	15
Figure 6	Precipitation map of Germany [[4]; 02.04.2012.]	16
Figure 7	Precipitation map of Switzerland [[4]; 02.04.2012.]	17
Figure 8	Precipitation map of Croatia [[4]; 02.04.2012.]	18
Figure 9	Graphic comparison of average monthly precipitation	19
Figure 10	Graphic comparison of average annual precipitation	20
Figure 11	Map of the Croatian motorway network [[7]; 05.04.2012.]	21
Figure 12	Urban pollution in stormwater [[9]; 12.04.2012.]	27
Figure 13	Contribution and major pathways of priority substances transport into surface waters in urban catchments (Becouze et al, no year)	31
Figure 14	Logarithmic chart of size ranges of some common particles (Schmollinger, 2012)	32
Figure 15	Geographical position of Croatia on map of Europe [[21]; 01.06.2012.]	62
Figure 16	Croatian climate zones [[22]; 02.06.2012.]	65
Figure 17	Theorethical boundaries of karstic region [[24]; 04.06.2012.]	70

Figure 18	Border line between Adriatic and Black sea basins (Loncar, 2010)	70
Figure 19	Existing and transportation networks planed by the end of 2020 [[23]; 03.06.2012.]	72
Figure 20	Planed development of Croatian highways (modified according to Croatian Association of Toll Motorways Concessionaires, 2012)	75
Figure 21	Possible solution of VBS (Malus, no year)	88
Figure 22	Grassed Swale (Malus, no year)	92
Figure 23	Example of Extended Detention Pond (EPA, 1997)	95
Figure 24	Constructed wetland with its consisting parts (EPA, 1997)	98
Figure 25	Schematic of Constructed Wetlands (Corson, 2006)	99
Figure 26	Plan view of a typical Wet Pond (WSDOP, 2011)	102
Figure 27	Infiltration Trench (Corson, 2006)	106
Figure 28	Complete Infiltration Basin (modified according to Malus, no year)	108
Figure 29	Layout example of Sand Filter (Malus, no year)	111
Figure 30	Cross section example of Sand Filter (EPA, 1997)	112
Figure 31	Examples of Litter Basket and Pitt (EPA, 1997)	117
Figure 32	Example of litter racks (EPA, 1997)	117
Figure 33	Multimedia water treatment filter [[14]; 18.05.2012.]	118
Figure 34	Oil/Grit Separator with sedimentation tank (CASQA, 2003)	123
Figure 35	Settling process in retarded laminar flow (Pfeffermann, 2011)	126
Figure 36	Typical rectangular horizontal flow sedimentation tank [[15]; 24.05.2012.]	127

Figure 37	Typical circular (radial flow) sedimentation tank [[15]; 24.05.2012.]	128
Figure 38	Sedimentation tank without permanent storage (Pfeffermann, 2011)	129
Figure 39	Sedimentation tank with permanent storage (Pfeffermann, 2011)	130
Figure 40	Cross view of typical Lamella Separator (Pfeffermann, 2011)	131
Figure 41	Lamella Separator with pipes [[17]; 26.05.2012.]	132
Figure 42	Generalized view of flow and sedimentation process in Lamella Separators [[16]; 26.05.2012.]	133
Figure 43	Typical Vortex Separator (Pfeffermann, 2011)	135
Figure 44	a) ‘Downstream Defender’ and b) ‘First Defense’ from Hydro International [[19]; 26.05.2012.]	137
Figure 45	Graphical view of evaluation grades for Wet Pond	160
Figure 46	Graphical view of evaluation grades for Infiltration Trench	161
Figure 47	Graphical comparison of possible solutions, i.e. treatment systems	161

List of Tables

Table 1	Impacts from increases in impervious surfaces (EPA, 1997)	10
Table 2	Average monthly and annual precipitation	19
Table 3	Standard runoff coeffcients for the rational method (Thompson, 2007)	25
Table 4	Rational method runoff coefficients (Schiariti, no year)	26
Table 5	Summary of pollutant in urban waters and specific measures (Sänkiaho, 2009)	34
Table 6	Pollution sources and parameters (Schmollinger, 2012)	35
Table 7	Example of established phosphorus TMDL (EPA, 2007)	43
Table 8	Protection zones for groundwater sources in fine grained porosity soils (modified according to OG 61/2011)	79
Table 9	Protection zones for groundwater sources in cracking and crackingcavernous porosity soils (modified according to OG 61/2011)	80
Table 10	Protection zones for surface water sources from reservoirs and lakes (modified according to OG 61/2011)	81
Table 11	Protection zones for surface water sources from open watercourses (modified according to OG 61/2011)	82
Table 12	Efficiencies for natural based treatments modified according to various resources	141
Table 13	Typical costs of BMPs presented in the form of dollars per cubic foot of treated stormwater (modified from EPA, 2006)	143
Table 14	Base costs of typical BMPs with excluded land costs (modified from EPA, 2006)	143

Table 15	Annual maintenance costs for BMPs (modified according to EPA, 2006)	144
Table 16	Types of soils with their infiltration rates and limitations of usage of BMPs (modified from EPA, 1997)	145
Table 17	Evaluation system for stormwater treatment facilities	150
Table 18	Efficiencies for technologies modified according to various resources	150
Table 19	Grades for stormwater treatment facilities based on their performances	151
Table 20	Evaluation of efficiency for Wet Ponds (WP)	151
Table 21	Grades for applicability of technologies compared to soil type	153
Table 22	Grades for area requirements	153
Table 23	Area required for construction of stormwater treatment facility (modified according to Young, 1996)	154
Table 24	Grades for Land Requirements	154
Table 25	Capital Costs according to treatment of stormwater from 2 ha site	156
Table 26	Maintenance Costs expressed as percentage of Capital Costs	156
Table 27	Grades for treatment facilities for maintenance costs (modified from EPA, 2006, Corson, 2006 and Caleb et al., 2006)	157
Table 28	Grades for frequency of ‘typical’ maintenance	157
Table 29	Grades range for sediment removal frequency for stormwater treatment facilities	158
Table 30	Stormwater treatment facilities grades for frequency of sediment removal	158

Table 31	Grades for Operational/Maintenance Costs for stormwater treatment facilities	159
Table 32	Grades for two fictional systems: Wet Pond and Infiltration Trench	159

List of abbreviations

A	catchment Area
Ag	silver
As	arsenic
BAP	Biologically Available Phosphorus
BOD_5	Biochemical Oxygen Demand (5-day period)
C	rational Coefficient
CC	Capital Cost
Cd	cadmium
COD	Chemical Oxygen Demand
Cr	chromium
Cu	Copper
CW	Constructed Wetlands
CWA	Clean Water Act
DBU	Deutsche Bundesstiftung Umwelt
DDT	dichlorodiphenyltrichloroethane
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall
E. coli	Escherichia coli
EC	Enterococcus bacteria

EDP	Extended Detention Ponds
(US)EPA	United States (of America) Environmental Protection Agency
EQSD	Enviromental Quality Standards Directive
FC	Fecal coliform bacteria
FOEN	Federal Office for the Environment
FOPH	Federal Office of Public Health
FWA	Federal Water Act
GS	Grassed Swale
Hg	mercury (Hg)
HM	Heavy Metals
i	rainfall (stormwater) intensity (l/s/ha)
IB	Infiltration Basins
IT	Infiltration Trenches
LR	Land Requirements
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MASH	Management of Stormwater on Highways
MOTH	Mineral Oil-Type Hydrocarbons
N^{tot}	Total amount of Nitrogen
NH_3-N	Ammonia-nitrogen

Ni	nickel
NPDES	National Pollutant Discharge Elimination System
NSDWR	National Secondary Drinking Water Regulations
NTU	Nephelometric Turbidity Units
O/MC	Operational/Maintenance Cost
OG	Official Gazette
OM	Organic matter
P^{tot}	Total amount of Phosphorus
PAH	Polynuclear aromatic hydrocarbons
Pb	lead
PCB	Polychlorobiphenols
SDWA	Safe Drinking Water Act
Se	selenium
SF	Sand Filters
SHARP	Sustainable Hydro Assessment and Groundwater Recharge Projects
SRP	Soluble Reactive Phosphorus
SST	Stormwater Sedimentation Tank
TC	Total coliform bacteria
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Loads

TOC	Total Organic Carbon
TPH	Total petroleum hydrocarbons
TSS	Total Suspended Solids
VBS	Vegetated Buffer Strips
VSS	Volatile Suspended Solids
WCA	Wastewater Charges Act
WFD	Water Framework Directive
WP	Wet Pond
ZN	zinc

1. INTRODUCTION

1.1. Problem description

Fundamental aspiration of any community is to grow, to evolve. Nowadays when we talk about growth, we talk about urban development. But development means nothing but changes. Changes that affect every aspect of our existence.

Rapidly growing cities require an extreme development of transport links and roads are exactly object of interest in the MASH[1] project and this Master thesis. More precisely, I will concentrate my work on the best and most frequently used treatments of stormwaters on highways in different countries and implementation of the best of these practices to the situation in Croatia. I will try to estimate if the situation in Croatia is satisfactory in relation to European legislation and try to compare already made facilities with examples made in developed countries. I think the importance of such analysis lies in the fact that Croatia will soon become a full member of the European Union and in accordance to that, further care should be taken to progress in certain fields in order to reach the standards of the more developed countries analyzed in this work.

All the changes that are made to the original enviroment bring along certain consequences. The most interesting consequence for us is the change of hydraulic properties of surface areas. By placing the road in a certain area we firstly replace original pervious layers with paved layers which are mostly impermeable[2]. Also the natural vegetation that protects the surrounding land from erosion gets removed. Prevention of water penetration into the soil changes even the groundwater flow regime. It can also lead to the appearance of concentrated stormwater flows that can cause further damage of both roads and natural enviroment.

[1] Management of Stormwater on Highways
[2] not allowing fluid to pass through

To avoid the negative consequences of 'development', a new branch of activity known as Stormwater management was founded. Stormwater management is the science of limiting negative impacts on the environment and enhancing the positive impacts, or catering for the hydraulic needs of a development while minimising the associated negative environmental impacts [CSIR, 2000.].

So my main task is to analyze what the stormwater management is like in Croatia and to make recommendations (if needed) based on conducted analysis.

1.2. MASH project

At the present time awareness about the bad effects of pollution coming from stormwaters is greater than ever. Therefore the leading institutions of the European Union launched a project that deals with this problems. The project is called MASH project, which stands for 'Management of Stormwater on Highways'.

Before this new initiative the focus of the EU was on the SHARP-project[3] which was focused on groundwater management and MASH-project is just a specific extension to the results from SHARP-project [Pfeffermann, 2011].

SHARP-project was focused on the exchange of innovative technologies to protect groundwater resources for future generations by considering the climate change and the different geological and geographical conditions of regions involved [[1]; 29/03/2012]. Member States[4] which took part in SHARP-project were Austria, Germany, Greece, Italy, Great Britain, Poland and Malta. The main target was the exchange of experiences on groundwater management between participating parties and as key contents of agenda were determined:

1. General groundwater management tools;
2. Artificial groundwater recharges technologies;
3. Groundwater monitoring systems;
4. Strategic use of groundwater resources for drinking water, irrigation and industry;
5. Techniques to save water quality and quantity;
6. Drinking Water Safety Plans including risk management tools;
7. Water balance models.

[3] Sustainable Hydro Assessment and Groundwater Recharge Projects (SHARP)
[4] member states of the European Union that were involved in project

MASH in the other hand is completely focused on stormwater management which means both treatment and disposal of it. According to Pfeffermann (2011) and from Krusic (2011) the MASH-project has the intended overall goal to handle road surface runoff more effectively by implementing three sub-goals:

- Part of the project is the intensive exchange of examples of good practice between countries with more experience (France, Netherlands, Germany, Austria) and those held with less experience (Italy, Slovenia, Poland). Thereby sustainable management of surface and groundwater will be promoted;
- Approaches and recommendations for possible action on local and regional policy level will be developed in order to reduce the task of the risks to the environment and further water pollution;
- The experiences made by regional cooperation should be integrated into policies. By incorporating the findings into the local and regional policies, they can be funded by the “European Regional Development Fund” (ERDF)[5] in the future.

Intensive building of modern and complicated transport infrastructure expresses increasing need for projects such as MASH, which can in a very simple way, by systematic analysis and further monitoring, optimize drainage of stormwaters from roads and solutions for potential pollution caused by them.

[5] In order to reduce the gap between the levels of development of the various regions and the extent to which the least-favoured regions and islands (including rural areas) are lagging behind, the ERDF contributes to the harmonious, balanced and sustainable development of economic activity, to a high degree of competitiveness, to high levels of employment and protection of the environment, and to equality between women and men

1.3. Objectives

In the last year, a few preparatory works which form part of the initial project (MASH) were made. Respected colleagues who were involved are M.-Eng. AnnaLisa Pfeffermann, Dipl.-Ing. Julia Rempp, B.-Eng. Kathrin Schmollinger, B.-Eng. René Ceko and B.-Eng. Nicolas Waltz. While Ms. Pfeffermann did her part in a master thesis the rest of students were involved by making their interdisciplinary projects. Along with this one, few other master thesis are being made as the part of MASH project at this moment.

The projects were done at the University of Applied Sciences RheinMain and in the cooperation with the State Institute of Highway and Transportation Hesse, Wiesbaden. The focus of my colleagues was on conditions in the Federal Republic of Germany and they have analyzed legislation, treatment technologies, pollution and monitoring programs for all the federal states[6].

My focus in the other hand will be on the conditions and state of the art in technical and natural based systems for the USA, Switzerland, Germany and Croatia. Also I will try to examine the differences in the legal frameworks for above mentioned countries. But the main goal is to give proposal of an development plan for Croatia based on the analyzed data from the more developed countries (USA, Switzerland, Germany).

[6] Germany is made up of sixteen states which are partly sovereign constituent states of the Federal Republic of Germany

1.4. Layout

In the first part of my work I will say something about the focus point of my work and few basic informations about MASH project on which my master thesis relate to.

In the second chapter (2. STORMWATER AND HIGHWAYS) firstly I will explain essentials about stormwater in general. After that I will show the differences (graphically) in the amount of precipitation for the countries in our focus. Next the basic terminology for highways, length of the roads for each country and most commonly used method (Rational method) for calculation of flow parameters from impervious areas will be explained. In the final part I will say something about pollution in stormwater. This part is mainly based on the informations from interdisciplinary project gathered by Ms. Schmollinger.

The third part (3. LEGISLATION) will be about legal frameworks in each country with exception of Germany and Switzerland which are partially subordinated to EU law. In the final part I will give summary on legal frameworks which should give general picture on different situations.

I will dedicate the next chapter (4. CROATIA AND ITS FUTURE DEVELOPMENT) to description of the basic information about Croatia and proposed development projects and urbanistic plans for Croatia in the near future and which are part of interest for this project. I will put an emphasis on karst terrains as these structures are characteristic for Croatia and very important parameter when it comes to management of stormwater. In final part I will describe determination and limitations of Croatian system for sanitary protection zones as this part is going to be directly related to recommendations for future development of Croatia.

Furthermore, the state of the art will be presented in the next chapter (5. STATE OF THE ART). Here, in short lines I will describe commonly used technical and natural based treatments in all the countries but with emphasis on the ones that could be transfered on Croatian situation. In the next part of chapter I will describe the performance parameters of the systems which are going to be used for determination of evaluation system in chapter 6. I will base this upon the informations from master thesis of Ms. Pfeffermann (for Germany) and upon the informations on the already made projects available on the internet (for other countries).

Furthermore in the next chapter (6. EVALUATION SYSTEM AND PROPOSAL OF DEVELOPMENT PLAN FOR CROATIA) I will present recommendations for new evaluation system for stormwater treatment facilities. Also I will present my proposals for future management of stormwaters on highways. My guidlines (recommendations) will be completely subjective and fully based on literature study and the analyses made in the previous chapters.

In the last chapter (7. CONCLUSION) I will make the final disussion on the questions answered in this project as well on the questions that still need to be answered.

All informations as well as recommendations in this master thesis will be based on literature studies. Due to language barrier and lack of quality projects accessible some parts should be taken with caution, especially parts of the performances of devices because data obtained and analyzed wasn't made by the same expert teams and wasn't derived in the same conditions.

2. STORMWATER AND HIGHWAYS

Stormwater represents runoff from urbanized area, the main caracteristic of which is devastated quality. Stormwater is generally conducted through various drainage systems and it can also include contaminated water, irrigation water and pavement washing water which has been discharged into the drainage system between the storm events (EPA[7], 2002).

In this chapter I will discuss basic parameters of stormwater as well as some causes of stormwater pollution. This is important to understand before conducting any future analysis. Also I will make the analysis on differences in the amount of precipitation in USA, Germany, Switzerland and Croatia and explain basic informations about highways which are our field of interest.

2.1. Stormwater in general

Stormwater is not a mechanical system. It is an enviromental process, joining the atmosphere, the soil, vegetation, land use and streams, and sustaining landscapes (Ferguson, 1998).

In nature, water is in constant process of circulation which is better known as hydrological cycle. Its total quantity doesn't change. It means that water can't be produced and it can't be destroyed. It just changes its aggregate state depending on surounding conditions. Because of that constant process of circulation we say it is a renewable resource. There are four main stages of hydrological cycle (figure 1):

- precipitation;
- surface runoff (flow);

[7] United States (of America) Environmental Protection Agency

- ground water (flow);
- evaporation and evapotranspiration.

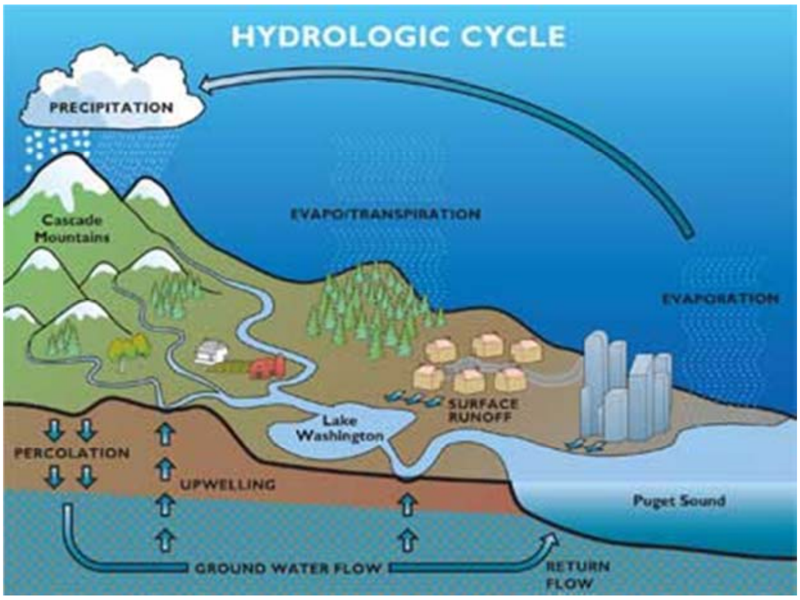

Figure 1: Graphic display of hydrologic cycle [[2]; 31.03.2012.]

If we look at water from a different point of view we can say that because of gravity, water attempts to flow in the direction of the largest fall choosing the way of least resistance so that dissipation of flow energy is reduced to a minimum. That means that natural way of water is to be partly absorbed and infiltrated into the soil and vegetation on which it falls.

Roots of trees, roots of grasses, beetles, ants, earthworms, they all make whole networks of micropores and macropores which represents the paths through which the water is moving in its natural way. By absorbing the water the soil continues hydrologic cycle and maintains its own health.

But development in any form usually involves the devastation of these systems and the appearance of many compact and impermeable surfaces. In the table 1 we can see how increasing of imperviousness can affect natural habitat.

Table 1: Impacts from increases in impervious surfaces (EPA, 1997.)

	Resulting Impacts				
Increased Imperviousness Leads to:	**Flooding**	**Habitat Loss (e.g., inadequate substrate, loss of riparian areas, etc.)**	**Erosion**	**Channel Widening**	**Streambed Alteration**
Increased Volume	*	*	*	*	*
Increased Peak Flow	*	*	*	*	*
Increased Peak Flow Duration	*	*	*	*	*
Increased Stream Temperature		*			
Decreased Base Flow		*			
Changes in Sediment Loadings	*	*	*	*	*

In the case where we have impervious layer present, the natural flow of water gets interrupted which causes changes of the whole ecosystem on different levels. When there is a natural system present (figure 2), rainfall gets infiltrated into the soil and pollutants are being removed, groundwater is being recharged and the stream base flows are being restored. But when there is impervious cover present (figure 3) direct runoff flushes pollutants directly into streams. In that case we also have floodings and uncontrolled erosion. Infiltration gets lost and groundwater declined. Wetlands go dry, aquatic systems dies and public water supplies gets declined.

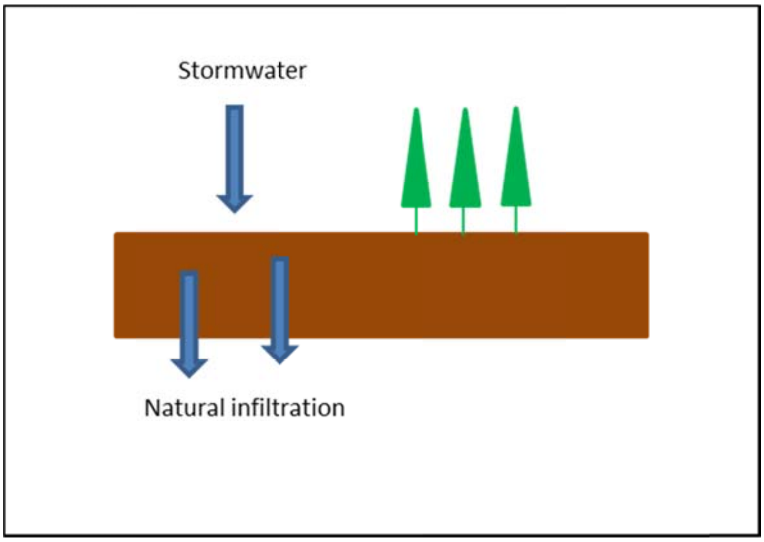

Figure 2: Infiltration of stormwater in undisturbed soil

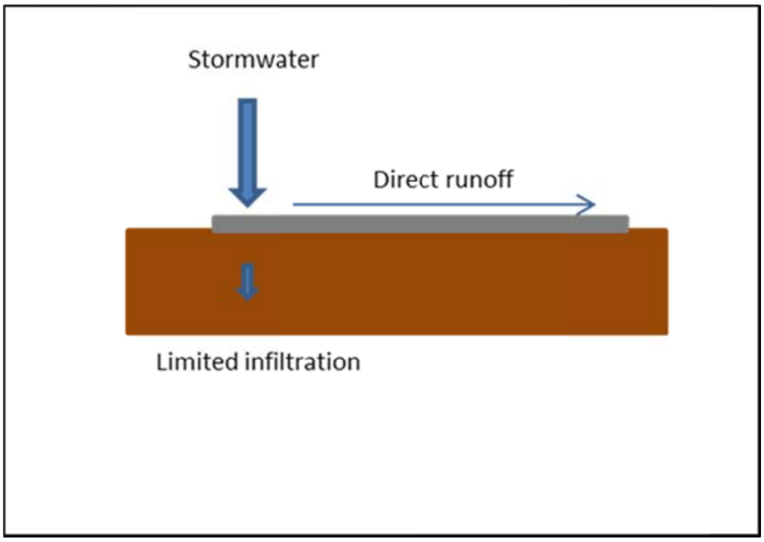

Figure 3: Limited infiltration because of impervious cover

As we see in figure 3, only small part of stormwater that falls on the impervious cover infiltrates in the soil. That is characteristic about which I will say a bit more in the next part of this chapter.

2.2. Precipitation analysis

As it was already mentioned before the analysis will be made on the example of four countries: USA, Switzerland, Germany and Croatia.

Precipitation is liquid or solid product of condensation or sublimation of water vapor, which falls from the clouds or is deposited directly from air on the ground. We have two types of precipitation. First is vertical precipitation which is caracterized as it is made in the clouds and than falls down to the ground. Second one is horizontal precipitation which is directly formed and deposited on the Earth's surface.

Forms of vertical percipitation are:

- rain,
- snow.
- hail, ...

Forms of horizontal percipitation are:

- rime,
- dew,
- drizzle,
- glaze, ...

The most usual forms can be seen in the figure 4.

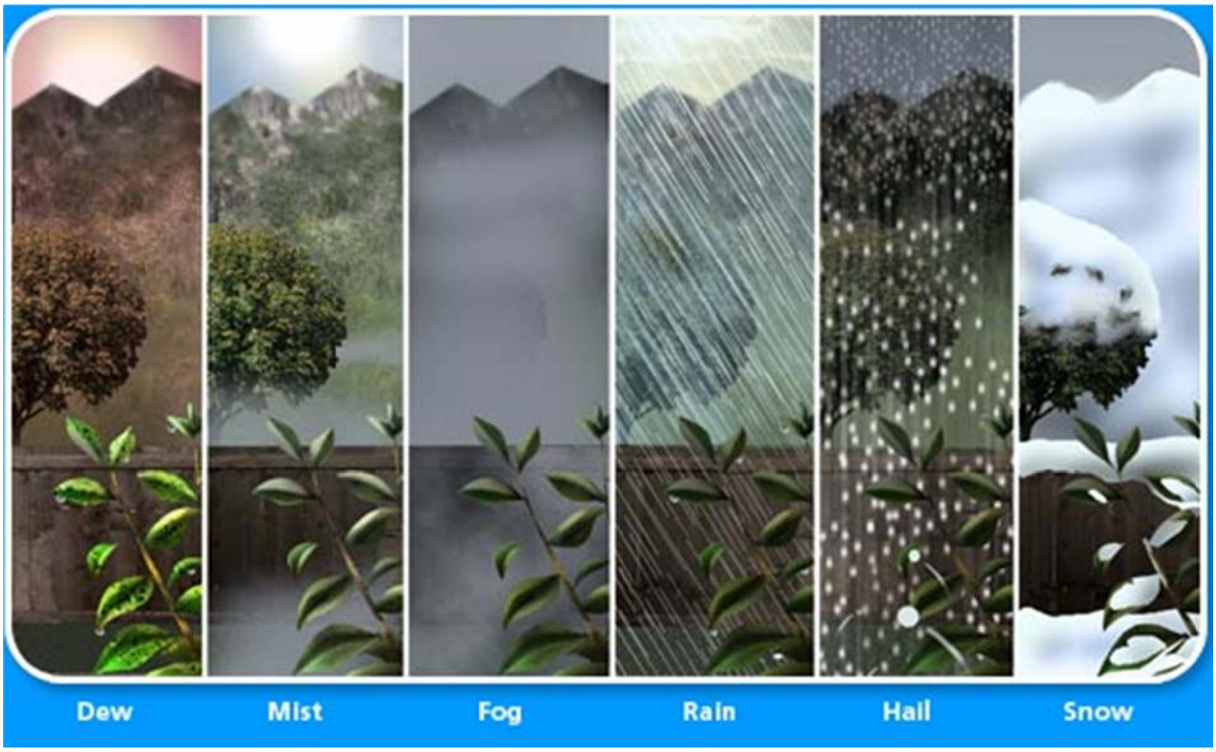

Figure 4: Forms of precipitation [[3]; 31.03.2012.]

It is well known that atmosphere is mostly consisting of gases. But besides gases in the atmosphere we can also find solid particles which are mainly aeorosoles[8]. The aerosoles are considered to be either natural (micron particles of sea salt, soil, volcanic ash, bacteria, spores, pollen), or artificial (primarily as a result of air pollution over the last few centuries). The role of aerosols in the formation of precipitation is significant because they represent condensing cores that participate in the formation of precipitation (Ozanic, 2012.). But primarily they represent pollutants that are distributed through the air and which finally end up on the Earth surface as a part of stormwater. Later in this chapter I will go more into details when it comes to pollutants.

[8] a colloid suspension of fine solid particles or liquid droplets in a gas

It's not only that building of impervious layers can destoy natural water flows but precipitation has also its harmful sides. It can cause erosion of the surrounding fields as well as the new founded creeks and torrents can have potential to destroy crops and to cause big material damages.

Precipitation is usually measured in milimeters (mm) and then we talk about height of precipitation. 1 mm of height corresponds to 1 liter per square meter of precipitation (l/m^2).

In the next few figures the precipitation zones will be shown based on the collected data for average amounts of precipitation for different countries. The difference in the average amount can be seen in the diversity of colours.

The colour scale is going from dark blue for regions with most precipitation and to white which stands for regions without any precipitation.

Figure 5: Precipitation map of USA [[4]; 02.04.2012.]

In figure 5 we can see a precipitation map for United States of America. It shows that the most of precipitation in the USA is concentrated on the coastal area, eastern and western. More accurately the zone of biggest concentration is in the southeastern coastal part and it extends to some degree to the central region and it covers states of Florida, Georgia, South Carolina, Alabama, etc. The other zone of great concentration is in the northwestern coastal part and it covers states of Washington, Oregon, Hawaii and in small part California. Generally speaking eastern part of USA has greater average amounts of precipitation. If we talk about states with highest and lowest amounts of precipitation then Hawaii is the state with highest annual average of 1618 mm and Nevada is the state with lowest annual average of 241 mm.

In the next figure (figure 6) we can see a precipitation map for Germany.

Figure 6: Precipitation map of Germany [[4]; 02.04.2012.]

The main caracteristic for Germany is that the precipitations are evenly distributed throughout the whole area. The region with the highest amount of precipitation is the area around Munich on south with annual average of 967 mm and the region with the lowest amount is the area around Berlin on north with annual average of 571 mm.

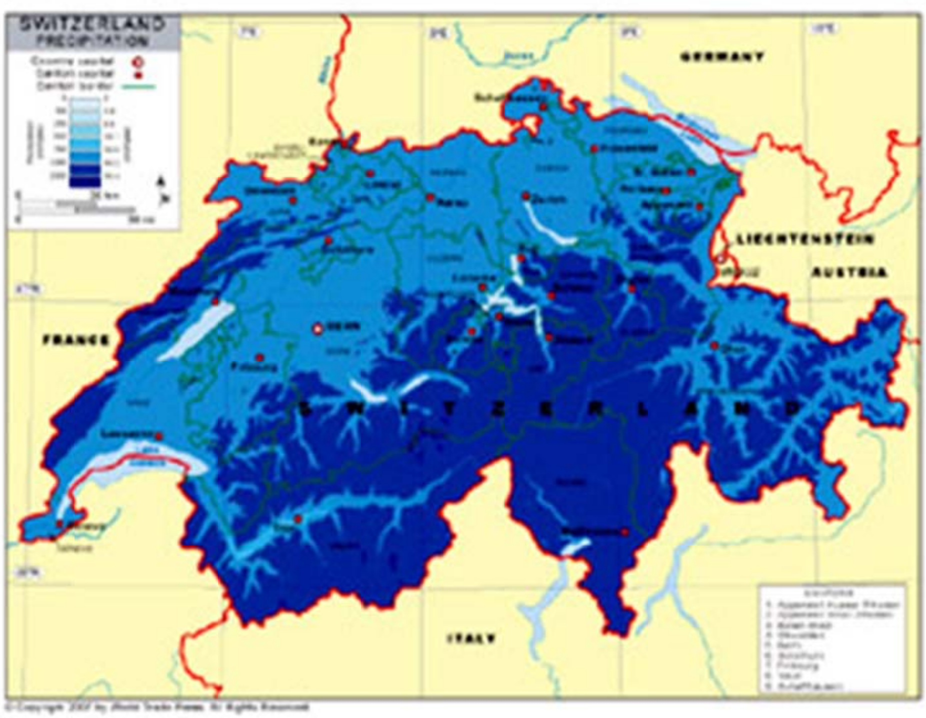

Figure 7: Precipitation map of Switzerland [[4]; 02.04.2012.]

Although from figure 7 we can asume that Switzerland has the same precipitation caracteristics as Germany it is not the case. The colour scale is only differently managed and in the Switzerland the region with highest amount of precipitation is the area around Locarno with annual average of 1668 mm and the region with the lowest amount is the area around Sion with annual average of 598 mm.

In the last map (figure 8) we can see precipitation regions for Croatia.

Figure 8: Precipitation map of Croatia [[4]; 02.04.2012.]

In Croatia the differences between precipitation regions are more pronounced than in other countries. The region with highest amount of precipitation is the area of Gorski kotar with annual average of up to 3500 mm and the region with the lowest amount is the area of eastern Slavonija around Osijek with annual average of 650 mm.

From gathered data about monthly precipitations [[5]; 04.04.2012.] we can see in table 2 range of average monthly and annual amounts for each country as well as the graphic comparison of obtained data (figures 9 and 10).

Table 2: Average monthly and annual precipitation

Month / State	Precipitation (mm)			
	Croatia	Germany	Switzerland	USA
January	56	46	61	84
Fabruary	54	40	54	68
March	47	33	59	96
April	59	42	68	85
May	86	49	93	103
June	95	65	123	88
July	79	73	119	108
August	74	69	116	120
September	70	48	101	100
October	88	49	70	78
November	89	46	68	75
December	67	43	54	75
Average (Y)	864	603	986	1080

Relations of obtained data for monthly precipitations are shown in figure 9 while relations for annual precipitations are shown in figure 10.

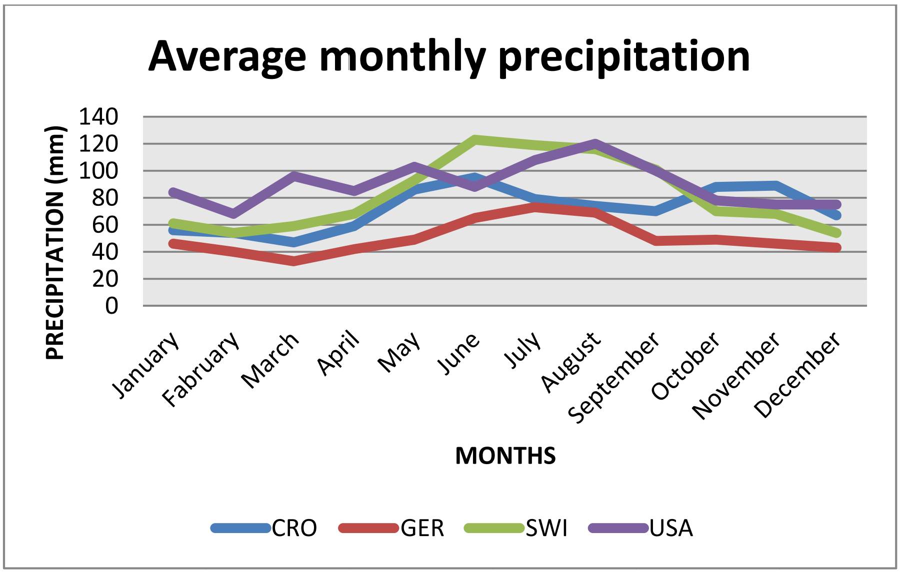

Figure 9: Graphic comparison of average monthly precipitation

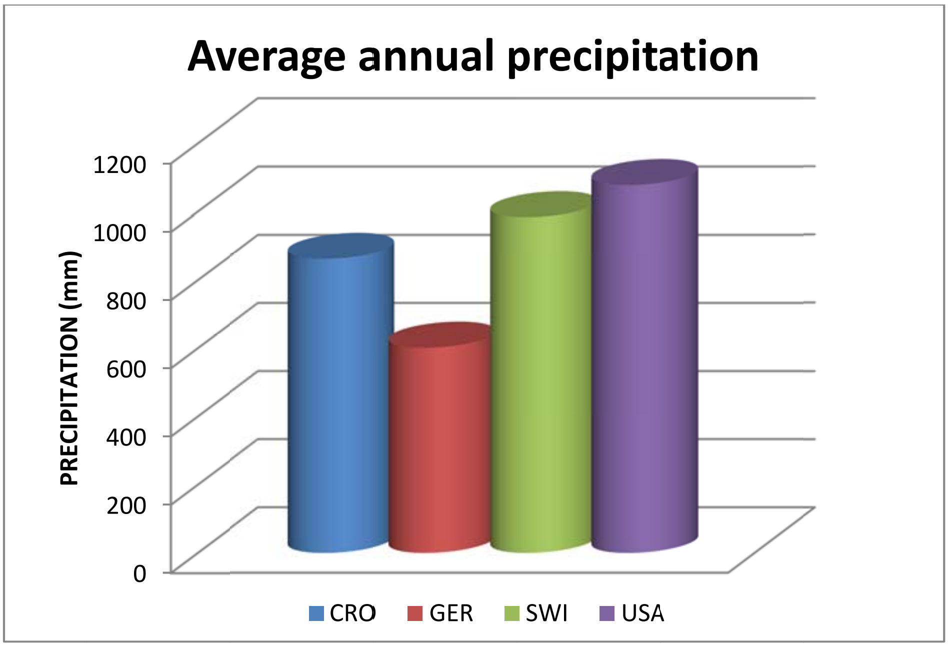

Figure 10: Graphic comparison of average annual precipitation

From the analysis we can see that the USA has the highest average annual precipitation (1080 mm) and that the Germany has the lowest one (603 mm).

2.3. Highways

A highway is any public road. Essential meaning depends on which region and speaking area we refer to. Highway designates major roads or any road open to the public. Any connected set of highways represent the highway system and every country has its own „national highway system“ [[6]; 05.04.2012.]. For example the USA has the largest highway system in the world which is 271900 km long while the longest highway is Australian „Highway 1“ which is 14500 km long.

As this work is based on the situations in certain countries the total lengths of their highways are:

- USA – 271900 km,
- Germany – 12800 km,
- Switzerland – 1763,6 km,
- Croatia - 1250,7 km (Figure 11).

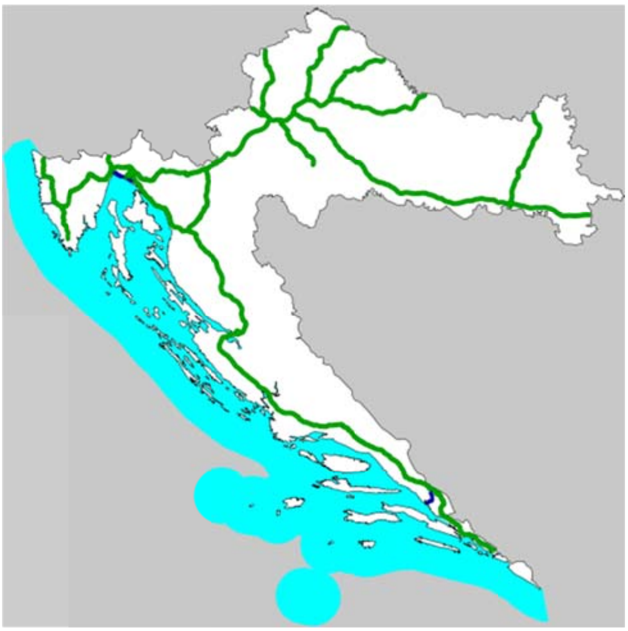

Figure 11: Map of the Croatian motorway network [[7]; 05.04.2012.]

When it comes to stormwater management we can think of highways as the one of the basic parameters of management. The length of highways in some country is indicator of development of that country and general economic status. The more the country is developed, the more the highways are present. With the increase of traffic the increase of potential pollution from roads gets presented. And according to that the stormwater management has to follow the development of road infrastructure in control, performance and technological terms .

Roads are usually border lines but also the centers of catchment areas. The water that comes to the road can't get infiltrated into the ground what is its primal intension. In this situation we can say that 90% of water that comes to the road surface runs off from it. That means that „runoff coefficient“ for that surface is 0,9. In the later stage of this chapter I will say something more about this coefficient and also about basic calculation method for dimensioning of stormwater treatment and regulation facilities.

2.3.1. Basic calculation method – „Rational method“

Sometimes for hydraulic designs, a complete hydrograph[9] of runoff

is not really required. The maximum (peak) of the hydrograph is suficient for design of the needed structure. Therefore, the design discharge is the maximum value of the flood runoff hydrograph (Thompson, 2007). A number of methods for estimating a design discharge have been developed and only one of them is 'The rational method' on which I will put my focus.

The rational method is basicly used to calculate the maximum flow from small catchment areas. The formula is

$$Q = C * i * A$$

where:

Q= design discharge (l/s),

C= rational coefficient (non-dimensional),

i= rainfall (stormwater) intensity (l/s/ha),

A= catchment area.

The formula is based on the assumption that the peak flow (design discharge) occurs in the time when entire catchment area is participating in the creation of flow, or when the time of storm duration is equal to the time of concentration.

For further analyses I will concentrate on rational coefficient as it is directly related to a problem of stormwaters on highway and their behaviour (flow regime).

[9] a graph showing the rate of flow (m^3/s) versus time past a specific point in a river, or other channel

2.3.2. Rational (runoff) coefficient

In the classical hydrological literature rational coefficient is incorrectly called runoff coefficient, which in fact represents the ratio between the effective precipitation and precipitation that falls on the basin.

Rational coefficient can not be treated as runoff coefficient because it is not constant during storm duration or even in all periods of the year [Ozanic, 2011]. Its size depends on:

- climatic characteristics of the area,
- characteristics of the catchment surfaces,
- infiltration,
- loss from vegetation and depressions,
- evapotranspiration.

But for the basic needs of calculation we take the generalized form which represents rainfall converted to runoff in a specific basin. The standard values, after Viessman and Lewis (Thompson, 2007), we can find in table 3.

Table 3: Standard runoff coeffcients for the rational method (Thompson, 2007).

Description	Runoff Coefficient
Business	
Downtown Areas	0.70–0.95
Neighborhood Areas	0.50–0.70
Residential	
Single-family	0.30–0.50
Multi-family detached	0.40–0.60
Multi-family attached	0.60–0.75
Residential suburban	0.25–0.40
Apartments	0.50–0.70
Parks, cemetaries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yards	0.20–0.40
Unimproved areas	0.10–0.30
Drives and walks	0.75–0.85
Roofs	0.75–0.95
Streets	
Asphalt	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Lawns; sandy soils	
Flat, 2% slopes	0.05–0.10
Average, 2%–7% slopes	0.10–0.15
Steep, 7% slopes	0.15–0.20
Lawns; heavy soils	
Flat, 2% slopes	0.13–0.17
Average, 2%–7% slopes	0.18–0.22
Steep, 7% slopes	0.25–0.35

When it comes to usage of racional method the great importance lies in the experience of engineer. It is really important that engineer knows how to estimate certain situation.

Although we are talking about tables with standard values of runoff coefficients there are different sources of informations so in some literatures we can even find some modified or just amended versions of coefficient values, like for example from Schiariti (no year), as we can see in table 4.

Table 4: Rational method runoff coefficients (Schiariti, no year)

Rational Method Runoff Coefficients

Type of Development		Runoff Coefficients
Business		
Downtown		0.70 to 0.95
Neighborhood		0.50 to 0.70
Residential		
Single family		0.30 to 0.50
Multi-units (detached)		0.40 to 0.60
Multi-units (attached)		0.60 to 0.75
Residential (suburban)		0.25 to 0.40
Apartment		0.50 to 0.70
Industrial		
Light		0.50 to 0.80
Heavy		0.60 to 0.90
Park, Cemeteries		0.10 to 0.25
Playgrounds		0.20 to 0.35
Railroad Yard		0.20 to 0.35
Unimproved		0.10 to 0.30
Character of Surface		
Pavement		
Asphalt and Concrete		0.70 to 0.95
Brick		0.70 to 0.85
Roofs		0.75 to 0.95
Lawns, Sandy Soil		
Flat	2%	0.05 to 0.10
Average	2% to 7%	0.10 to 0.15
Steep	7%	0.15 to 0.20
Lawns, Heavy Soil		
Flat	2%	0.13 to 0.17
Average	2% to 7%	0.18 to 0.22
Steep	7%	0.25 to 0.35

Source: Design and Construction of Sanitary and Storm Sewers, American Society of Civil Engineers and the Water Pollution Control Federation, 1969.

2.4. Hazardous substances (pollution) in stormwaters

A pollutant is the direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the enviroment (EU WFD[10], 2000/60/EC). But for the purposes of this paper we can say that pollutant is a of human origin substance that contaminates some media, in our case water (figure 12). Pollutants can be a chemical, inorganic substances such as DDT in water (insecticides), chemicals, heavy metals (especially heavy metals accumulate in the roots of plants like beetroot, carrots, etc.) or organic material (eg, E. coli in the water - fecal contamination), the biological substrates, blood, microorganisms, etc.

Figure 12: Urban pollution in stormwater [[9]; 12.04.2012.]

[10] Water Framework Directive

It is used to associate water pollution with heavy industry but the pollution as part of stormwaters is produced by every one of us. When there is any kind of precipitation present, the water moves over the ground and also picks up the chemicals which are of human origin:

- oil from our cars,
- fertilizers,
- herbicides and insecticides,
- pet and livestock wastes (bacteria and nutrients),
- faulty septic systems, etc.

Urbanization increases the variety and amount of pollutants transported to receiving waters (EPA, 2002) The chemical characteristics of stormwater are dependent on the nature of surfaces (roads, roofs etc.) with which it comes into contact during the runoff process as well as natural processes and anthropogenic activities in the catchments. The different types of pollutants may cause problems during utilisation, detention or discharge of stormwater to the environment and may pose specific demands to decentralised treatment (Eriksson et al., 2007).

Land alterations increases the rate and amount of runoff (stormwater) from the catchment area entering the stream. This water carries pollutants, erodes stream channel and banks, and destroys instream habitat. Also sediments (dirt and sand on roads, driveways, and parking lots or eroded sediment from disturbed surfaces (e.g. construction sites) enters stream with stormwater runoff and it smothers aquatic habitat, depletes oxygen, reduces water clarity, and carries nutrients and toxic contaminants. Stormwater also contains nutrients which originate from excess fertilizers on lawns or fields, failing septic systems, and animal waste. Nutrients can stimulate excessive plant growth, it lowers dissolved oxygen levels, degrades aesthetics and destroys native aquatic life. Also the bad caracteristic of stormwater is its temperature. Warmer water caused by runoff from impervious surfaces, removal of streamside vegetation, and reduction in groundwater flows can prove to be harmful for cold water species. It promotes spread of invasive species and excessive plant growth while it reduces dissolved oxygen levels in water.

Stormwater also contains bacterias and heavy metals (toxic contaminants). Bacterias are potentially pathogenic microscopic organisms in failing septic systems, sewer overflows, and animal waste which can be harmful to humans (untreated waste can cause numerous diseases). Heavy metals which we can found in cleaning compounds, pesticides and herbicides and vehicle leakage of oil, gas, etc. can be harmful to humans and aquatic life already at fairly low levels and many of them resist breakdown and can accumulate in fish and other animal tissues (including human), and can lead to mutations, hard disease, or cancer.

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 (Schmollinger, 2012). Weather conditions in some region are crucial to the amount of pollutants that appear in stormwaters. Long dry periods allow a longer deposition of harmful substances, and therefore greater quantities are taken away during the precipitation cycles.

According to EU WFD (2000/60/EC) main pollutants in stormwater are:

- organohalogen compounds and substances which may form such compounds in the aquatic environment,
- organophosphorous compounds,
- organotin compounds,
- substances and preparations, or the breakdown products of such, which have been proved to possess carcinogenic or mutagenic properties or properties which may affect steroidogenic, thyroid, reproduction or other endocrine-related functions in or via the aquatic environment,
- persistent hydrocarbons and persistent and bioaccumulable organic toxic substances,
- cyanides,
- metals and their compounds,
- arsenic and its compounds,
- biocides and plant protection products,
- materials in suspension,
- substances which contribute to eutrophication (in particular, nitrates and phosphates),
- substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD[11], COD[12], etc.).

[11] Biochemical Oxygen Demand - amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period

[12] Chemical Oxygen Demand – it is a test commonly used to indirectly measure the amount of organic compounds in water

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) (Schmollinger, 2012).

According to Sänkiaho (2009) and from Beretta et al. (2007) the generation of polluted stormwater is caused by two separate processes. During dry weather the pollutants will accumulate on surfaces, and when the rainfall intensity[13] is high enough it will cause the detachment and transportation of the pollutants (figure 13). The build up process is caused by dry deposition of dust, human activities, traffic, wind and erosion, and the accumulation will increase exponentially in time. Also the length of the dry period preceding a storm will greatly affect stormwater quality.

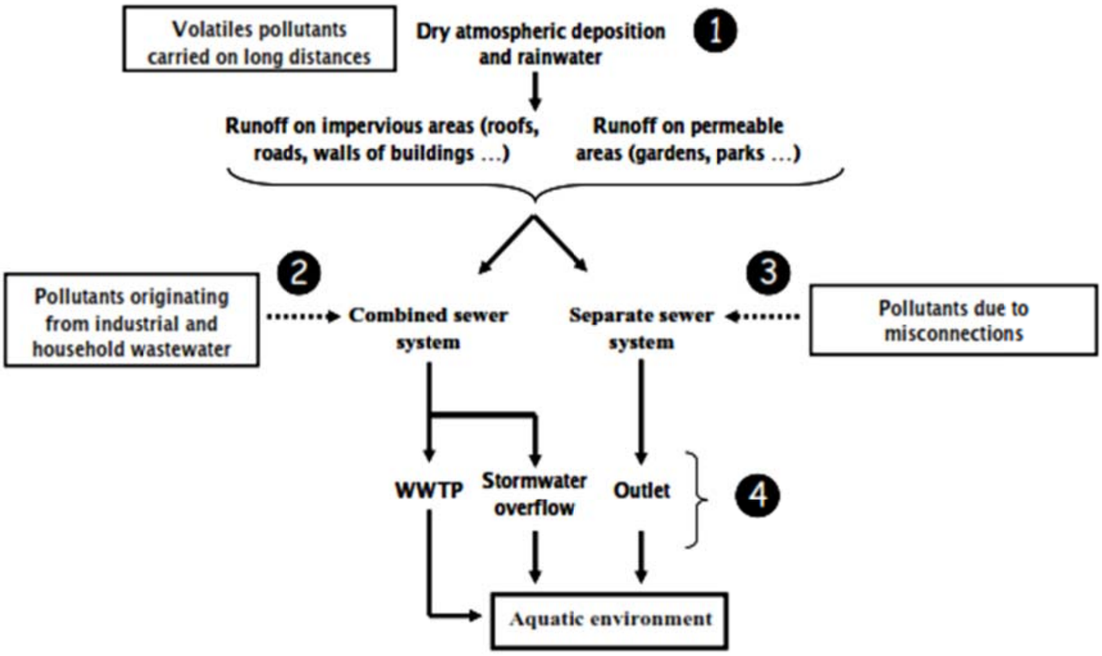

Figure 13: Contribution and major pathways of priority substances transport into surface waters in urban catchments (Becouze et al., no year)

[13] The precipitation (rainfall) intensity is a measure of the amount of rain that falls over time i.e. the height of the water layer covering the ground in a period of time (usually mm/min)

In figure 13 atmospheric deposition on surface (dry atmospheric deposition and rainwater) is marked 1. Mark 2 denotes household and industrial wastewater and sediments deposited during dry weather. While mark 3 denotes misconnections mark 4 shows discharge from overflows and outlets into the aquatic environment during storm events.

According to Schmollinger (2012) well degradable substances have less harmful effects on the environment than persistent pollutants. 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.

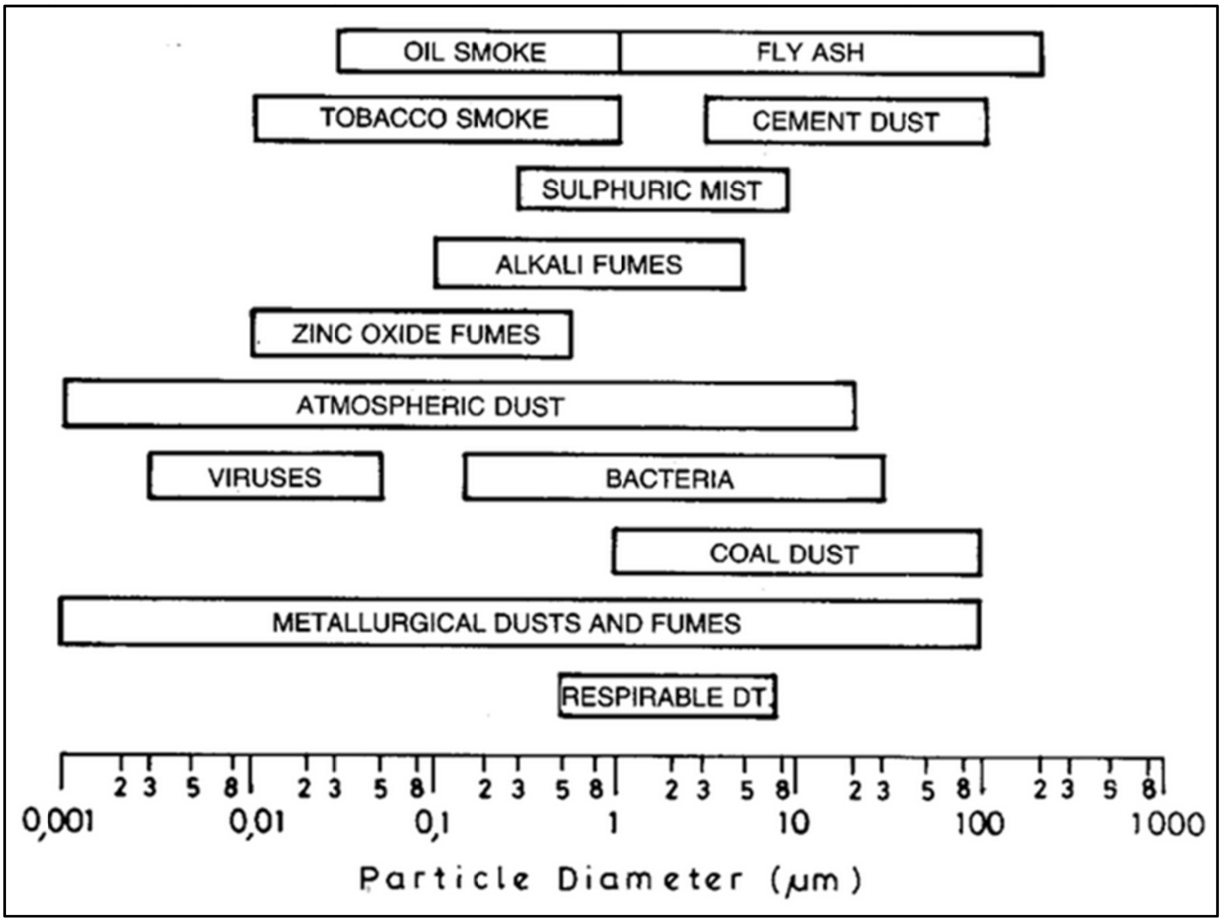

Figure 14: Logarithmic chart of size ranges of some common particles (Schmollinger, 2012)

2.4.1. Common pollutants and their sources

The composition of pollutants in stormwater depends mainly on local conditions, i.e. on the use of analyzed surface and catchment areas. Every action brings with it a particular activity, characteristics, and finally the pollutants. Quality analysis and monitoring are the foundation of a good stormwater management. Load of pollutants is a key factor for the selection and design of an appropriate system for stormwater purification.

While all activities can be a source of some contaminants, certain activities are particularly large contributors [[8]; 10.04.2012.]. Industrial sites can be major sources of metals and organic chemicals. Feedlots are a large source of pathogens, nutrients, and BOD. Agricultural and timber operations discharge high quantities of sediment. According the same source we can see that we have seven categories of the pollutants commonly occurring in stormwater:

- heavy metals (includes: zinc, cadmium, copper, chromium, arsenic, lead),
- organic chemicals (includes: pesticides, oil, gasoline, grease),
- pathogens (includes: viruses, bacteria, protozoa),
- nutrients (includes: nitrogen, phosphorus),
- Biochemical Oxygen Demand (BOD) (includes: grass clippings, fallen leaves, hydrocarbons, human, and animal waste),
- sediments (includes: sand, soil, and silt),
- salts (includes: sodium chloride, calcium chloride).

There are also other sources that expand this categories reffering to many different stormwater quality studies. For example we have the next table (table 5) and according to Sänkiaho (2009) reffering to Shaver et al. (2007).

Table 5: Summary of pollutant in urban waters and specific measures (Sänkiaho, 2009)

Pollutant Category	**Specific Measures**
Solids	Settleable solids Total suspended solids (TSS) Turbidity (NTU[14])
Oxygen-demanding material	Biochemical oxygen demand (BOD) Chemical oxygen demand (COD) Organic matter (OM) Total organic carbon (TOC)
Phosphorus (P)	Total phosphorus (TP) Soluble reactive phosphorus (SRP) Biologically available phosphorus (BAP)
Nitrogen (N)	Total nitrogen (TN) Total Kjeldahl nitrogen[15] (TKN) Nitrate + nitrite-nitrogen (NO_3+NO_2-N) Ammonia-nitrogen (NH_3-N)
Metals	Copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), arsenic (As), nickel (Ni), chromium (Cr), mercury (Hg), selenium (Se), silver (Ag)
Pathogens	Fecal coliform bacteria (FC) Enterococcus bacteria (EC) Total coliform bacteria (TC) Viruses
Petroleum hydrocarbons	Oil and grease (OG) Total petroleum hydrocarbons (TPH)
Synthetic organics	Polynuclear aromatic hydrocarbons (PAH) Pesticides and herbicides Polychlorobiphenols (PCB)

[14] the units of turbidity from a calibrated nephelometer are called Nephelometric Turbidity Units (NTU)

[15] amount of nitrogen obtained from method for the quantitative determination of nitrogen in chemical substances developed by Johan Kjeldahl

Although pollutants which can be found in stormwater may come from various sources that are not directly connected with the traffic and roads (for example, substances used for agricultural purposes, which may be transferred by air from distant fields to certain roads), the highest contamination comes exactly from the traffic.

Traffic contributes with a number of different types of pollutants to urban stormwaters. Pollutants originate from automotive fluids, deterioration of automotive parts, and vehicle exhaust. Also other traffic sources of pollutants are tire wear, used motor oil and grease, vehicle rust, engine coolants and antifreeze. Concentrations of this pollutants can often exceed acute toxicity levels. In the table 6 which was taken from Schmollinger (2012) and according to RiStWag and supplemented from Winkler (2005) we can see different traffic pollution sources and relevant parameters that originate from these sources..

Table 6: Pollution sources and parameters (Schmollinger, 2012)

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, 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

When it comes to analysis of quality of stormwaters, i.e. amount of pollutants in stormwaters there is no unique regulation on which the analysis and evaluation is done but the analysis of individual pollutants that are regarded as the best indicators of the general state of the system, which is determined according to local conditions and recommendations for specific sites.

Generally speaking, according to many sources, i.e. analysis, the following pollutants are taken as the most important subjects of analysis (modified according to the analysis of East-West Gateway Coordinating Council (2000) and DWA[16] and DBU[17] (2010)):

- Total Suspended Solids (TSS)*/**,
- Volatile Suspended Solids (VSS) */**,
- Total Organic Carbon (TOC) */**,
- Chemical Oxygen Demand (COD) */**,
- Nitrite and Nitrate*/**,
- Total Kjeldahl Nitrogen (TKN)*,
- Phosphate, Phosphorus*/**,
- Copper*/**,
- Lead*/**,
- Zinc*/**,
- Cadmium**,
- Mineral Oil-Type Hydrocarbons (MOTH)**,
- Polycyclic Aromatic Hydrocarbons (PAH) – (key component benzo(a)pyrene)**,
- Chloride**.

* - pollutants according to East-West Gateway Coordinating Council

** - pollutants according to DWA and DBU

16 Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall - German association for water management, waste and wastewater

17 Deutsche Bundesstiftung Umwelt – German federal environment foundation

3. LEGISLATION

Legislation (legal frameworks) is a set of principles and rules that support some established structure and help you form your decisions in accordance to these principles.

Every country has its own way of dealing with stormwaters. This means that every country also develops some specific and usually different legal frameworks along with different aspects of management of stormwaters. In general, all the types of legal regulations dealing with water issues are called „The water law“. The water law covers a wide array of subjects and categories providing a legal framework relating to water (public waters, surface waters, ground water,...)

In this chapter I will discuss and compare legal frameworks in the USA and Croatia as well as in Switzerland and Germany but within boundaries of the European Union (EU) laws – European Union Water Framework Directive (EU WFD).

In conclusion of the chapter I will present the summary of analysed legislatives in all the countries to establish differences and to see which legal frameworks are most comprehensive, and most rigorous when it comes to prosecuting potential poor disposers.

3.1. The law in the USA

In the United States of America there is a complex,but very efficient, legal system when it comes to water rights. They derive their legal authority from various laws, codes, mandates, ordinances and regulations enacted by the federal and state legislature. Legislative ranges from a primary and major Federal laws and requirements, across State laws and requirements up to Regional, Municipal and Local Requirements.

The beginning of modern stormwater quality studies can be traced to United States in late 1960's. Ever since then the USA has been the leading country when it comes to these kind of studies. The American stormwater legislation and their studies have been reference point for many studies around the world.

At the moment the Environmental Protection Agency (in future text EPA) is charged in the USA with regulating stormwater in general and thus the stormwater from highways. EPA stands for the United States Environmental Protection Agency so sometimes it is shortened as USEPA. It began its activities in December of 1970 and it is an agency established by the federal government of the United States. EPA's main goals are protecting human health and environment and they do it by writing and conducting regulations based on laws. EPA operates in 10 regions which spread across the country and has 13 different offices which are responsible for numerous problems and some of them are for example:

- Office of Environmental Information,
- Office of Chemical Safety and Pollution Prevention,
- Office of Air and Radiation,
- ...
- and the most important for us - Office of Water.

There are two main laws that regulate surface and ground water quality in the USA:

1. The Clean Water Act (CWA),
2. The Safe Drinking Water Act (SDWA).

CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters [[10];22.04.2012.]. CWAs beginnings trace all the way back to 1948[18] but the Act was significantly reorganized and expanded in 1972[19].

The biggest amendment was that the CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless the discharge is in compliance with a NPDES[20] permit. In the USA the stormwaters are subjected to water quality standards defined with the CWA and after entering any kind of concentrated flow the stormwaters are classified as point source discharge. EPA's NPDES permit programs primarily objective is to control discharges of any kind of polluted waters. The NPDES permit program is authorized by CWA in its section 402. Point sources are discrete conveyances such as pipes or man-made ditches [[10]; 22.04.2012.]. Individual homes that are connected to a municipal or local system, use a separate septic system, or in general do not have a surface discharge do not need an NPDES permit. On the other hand, industrial, municipal, and other facilities must obtain NPDES permits if their discharges go directly to surface waters. Highways which are the subject of my research fall under nonpoint sources of pollution so I will dedicate in the continuation to particulars and specificities relating to this type of pollution, i.e. nonpoint sources.

The CWA is consisting from numerous sections which cover all the questions as well as the future steps of development in any form associated with the water estates. Section which is most important for us is section 319. This

[18] back then it was called the Federal Water Pollution Control Act (FWPCA)
[19] Clean Water Act (CWA) became the Act's common name
[20] National Pollutant Discharge Elimination System

section is about nonpoint source management. It provides water quality standards, criterias, and guidelines.

The main item is the initial identification of waters and water areas where water quality required in this Act can not be preserved without further actions of the control and regulation of nonpoint source pollution. Also it identifies categories and subcategories of nonpoint sources or particular nonpoint sources which add significant amount of pollution to water areas. It describes the processes for identifying best management practices and measures to control each category and subcategory of nonpoint sources and identifies and describes State and local programs for controlling pollution from nonpoint sources. In order to meet all the requirements of this section other sections from CWA used as base are sections 208, 303, 304, 305, and 314. In the section 303(d) the CWA also requires the establishment (by each state) of Total Maximum Daily Loads[21] (TMDLs) which specify allowable pollutant loads from all sources (point, non-point, and natural) for a given watershed. In the next table (table 7) we can see an example for phosphorus TMDL established to meet an allowable in-stream concentration (location is not familiar).

[21] TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards

Table 7: Example of established phosphorus TMDL (EPA, 2007)

Example loads	Winter	Spring	Summer	Fall
Allocation: Seasonal load (kg/season)	370,080	247,860	191,700	229,230
Seasonal daily average (kg/day)	4,112	2,754	2,130	2,547
Seasonal 50th percentile (kg/day)	153,504	86,680	121,561	171,456
Seasonal daily maximum (kg/day)	324	433	101	121
Seasonal 75th percentile (kg/day)	3,010	1,651	589	1,012
Seasonal 95th percentile (kg/day)	19,074	15,489	10,954	11,141

EPA also oversees states, local governments and water suppliers to enforce the standards, under the Safe Drinking Water Act. The program primarily includes regulations to protect underground sources of drinking water, source-water protection methods and protection of public health by establishing drinking water standards and it applies to all public water systems in the USA. To ensure that drinking water is safe, SDWA sets up multiple barriers against pollution. These barriers include: source water protection, treatment, distribution system integrity, and public information [[11]; 22.04.2012.]. Under the SDWA EPA prioritizes legal limits of contaminants for potential regulation based on risk and how often they occur in water supplies. This limits are product of the level that protects human health and the level that water systems can achieve using the certain technology and the list of acceptable techniques for treating contaminated water. Beside limits EPA also determines how often and in what manner the analysis of these prescribed contaminants must be carried out.

SDWA as a federal act gives individual states the chance to set and conduct their own drinking water standards as long as the standards are at least as strong as EPA's national standards.

As the addition to CWA and SDWA, EPA also conducts National Primary Drinking Water Regulations (NPDWRs) or primary standards[22] which are legal standards for public water systems. NPDWRs are used to protect public health by limiting the levels of contaminants in drinking water. Within NPDWRs there are 2 most important terms: Maximum Contaminant Level Goal (MCLG) and Maximum Contaminant Level (MCL). MCLG presents the striving level of a contaminant in drinking water. Below MCLG there is no expected risk to health. MCL is the highest level of a contaminant allowed in drinking water and it's an enforceable standard.

Also there are National Secondary Drinking Water Regulations (NSDWRs) or secondary standards[23]. Secondary standards include contaminants that may cause cosmetic effects (skin changes,...) or aesthetic effects (such as taste, odor,...) in drinking water but that are not toxic for public health.

[22] standards which include contaminants potentially dangerous for public health (f.e. coliforms, viruses, etc.)
[23] non-enforceable standards for contaminants that are harmful but not life threatening

3.2. The EU law

Legal frameworks of member states of EU are shaped by legal norms based on EU law. According to Pfeffermann (2011) European law overrides the federal law. When it comes to environmental, climate and energy issues the European Community can implement laws superior to the law of the Member States and due to the Maastricht Treaty[24] and the Lisbon Treaty[25]. For member states within the European Union it is really important to have unified water-related directives for water resource management and environmental and water quality standards. The main directive from EU concerning this problems is the Water Framework Directive which has two basic goals:

- getting Europe 's waters cleaner,
- and getting the citizens involved.

The Water Framework Directive (WFD) is the most important EU directive in the water field issued in 2000. after long time of preparing and adjustment. Basic objective is to improve the ecological status of surface and groundwaters. The objectives are presented in Article 4 where both the requirements and deadlines for obtaining them are listed. As it is written in the Directive (2000/60/EC) the fields of interest affected by this directive are:

- surface water,
- wetlands,
- groundwater,
- heavily modified and artificial waters.

[24] signed on 7 February 1992 - determined the foundations of modern EU
[25] an international agreement that amends Maastricht Treaty

A 'good status' should be achieved by Member States by the end of 2015. This term incorporates both chemical parameters (low pollution levels) as well as ecological ones (healthy ecosystems). As it is seen in section 1 of WFD 'good status' stands for 'good chemical status' and 'good ecological status' referring to surface waters and 'good chemical status' and 'good quantitative status' referring to groundwater. 'Good quantitative status' can be explained as a balance between usage and recharge of groundwater bodies.

One of the most important requirements in WFD is water management based on river basins[26] - the natural geographical and hydrological units instead of usual administrative and governmental boundaries (f.e. Schelde or Rhine river basins). In this way it is secured that the entire catchment of a river will be treated as one ecological and hydrological entity. This will help to end the sectoral and often separate administration of river catchments by a host of independent authorities with little or no common planning (Hall et al., 2004). This groundbreaking rule commits EU member states to set up river basin districts and the administrative units for each district sometimes traversing national frontiers and in the end contributing to better and more transparent management of European waters. That means where a river basin includes more than one member state (neighbor countries), an international river basin district must be created. According to WFD every „river basin management plan“ needs to be updated every six years which provides quality basis for sustainable development of water resources within the EU.

The WFD (2000/60/EC) also requires background values for naturally occurring substances and close to zero for man-made synthetic substances. The list of 33 priority and 8 other important substances, including the priority hazardous substances, was issued as the Annex X of WFD. In the Directive hazardous substances are defined as 'substances or groups of substances that are toxic, persistent and liable to bio-accumulate, and other substances or groups of substances which give rise to an equivalent level of concern'.

[26] the portion of land drained by a river and its tributaries

The final list of 33 priority and 8 other pollutants was defined by the WFDs 'daugther directive' – Directive on Enviromental Quality Standards or more commonly Enviromental Quality Standards Directive (EQSD) and in 2008. Also we can find it under the name Directive 2008/105/EC. There were some major alterations of basic Directive made by EQSD. Primarily 15 additional priority substances were provided from which 6 of them were marked as priority hazardous substances. Also two existing priority substances were designated as priority hazardous substances. The possibility of applying enviromental quality standards for sediment and biota[27] instead for water and stricter standards for four existing substances were another changes made to WFD. Also by replacing five older directives it contributed to easier, better and generally more effective regulation and implementation of rules.

Few other important directives related to WFD are:

- Directive on Dangerous Substances (2006/11/EC),
- Directive on Urban Waste Water Treatment (91/271/EEC),
- Groundwater Directive (2006/118/EC).

From these three additionally specified directives Groundwater Directive in particular stands out due to the specific issues it deals with. Because of the nature of groundwater flow and in case of contamination of groundwater, contamination is practically impossible to remove. Although such a flow has the characteristic of purification by filtration through the various layers through which it runs, that is a long lasting process in which in the end, people can be seriously threatened.

[27] the total collection of organisms of a geographic region or a time period

3.3. Law in the Federal Republic of Germany

The informations about the law structure in Germany were mainly retrieved from the works of Pfeffermann (2011) and Schmollinger (2012).

According to Pfeffermann (2011) The most important federal laws and regulations when it comes to management of stormwater on highways are:

- the Federal Water Act,
- the Wastewater Ordinance,
- the Federal Soil Protection Act,
- the Wastewater Charges Act,
- the Soil Protection Ordinance.

The law binding situation in Germany is quite unique. As Germany consists of 16 federal states every state has its own specific laws. As the EU laws are superior to the German national laws so are the German national laws superior to the federal states laws. Generally, the EU WFD was implemented into the German water laws through Federal Water Act (in future text FWA) and FWA is supposed to be the foundation of any water act brought by federal state. According to the same source only some states effectively apply the basic clauses of the Federal Water Act along with adopting their own specific laws on the matter that has not been regulated to the full extend by the Federal Republic of Germany. Most of the states only refer to the given Federal laws which can be insufficient in certain situations.

According to Schmollinger (2012) the Federal Water Act is the basic water law in Germany and its main goal is to regulate hydrologic balance, supply and distribution of water. The purpose of this law is the water management in accordance to sustainable development[28] while preserving water as a part of the ecosystem, as the basis of human existence and development and as habitat for aquatic flora and fauna. In FWA stormwater is formally classified as wastewater and the disposal of it includes collection, drainage, treatment, discharge, percolation and irrigation. The discharge must be consistent with the water quality requirements defined by the FWA. It also advocates separate sewage systems as the best way of dealing with stormwater. Unfortunately, like in the many diverse national laws, the treatment and disposal of stormwater from highways is not especially represented.

Wastewater Ordinance sets minimum requirements for regulatory permissions to release wastewater into receiving water (Schmollinger, 2012). It also determines the methods and frequency of measurement. Specific parameters and limit values are given through several attachments but the treatment of stormwater from highways is not specifically mentioned. Although it refers mostly to industrial branches it is applicable to all wastewater treatment methods.

Priority goal of the Federal Soil Protection Act is protecting soil from contamination and deterioration and regeneration of its natural characteristics. It advocates a ban of any changes to soil properties and the renovation or removal of contaminated parts. The natural role of soil in the ecosystem must be preserved. According to the Federal Soil Protection Act under the term 'natural

[28] a pattern of economic growth where resource use aims to meet human needs while preserving the environment so that these needs can be met for future generations

good soil' all unsaturated[29] and saturated zones as well as soil liquefied[30] by groundwater or percolation water are included (Schmollinger, 2012).

According to Pfeffermann (2011) the Wastewater Charges Act (WCA) is a principal act when it comes to regulating the obligatory and penalty payments for the discharge of wastewater into waters. According to WCA water and stormwater in the developed and/or paved areas are labeled as wastewater. In that case discharging of stormwater into water bodies is not penalised but only taxable if made as an indirect discharge through a public sewer and then the FWA can't be applied.

The Soil Protection Ordinance supplies the Federal Soil Protection Act with provisions for enforcement of its main goals and based on previous specification of the existing issues. According to Schmollinger (2012) and from Pfeffermann (2011) conditions for taking samples and the analysis of it are specified. Also precautionary, test and action values are determined. These values are often applied to determine the quality and retention performance of soil or the contamination potential of contaminated stormwater.

[29] a condition in which some but not all pores between soil particles are temporarily or permanently filled with water – a condition where all pores are filled with water is called saturated zone (soil)

[30] saturated, unconsolidated soil which is transformed into a substance that acts like a liquid

Along with the above mentioned laws there are also some technical guidelines and standard specifications which are not legally binding but which are composed on the basis of detailed analysis and conclusions of the experts. Their use is recommended especially if certain prescribed laws do not exist or laws are not clearly defined for certain problems . Some of these guidelines and specifications are:

- ISO standards (International Standardization Organization),
- EN/DIN standards (German Institute for Standardization),
- RAS regulations (RAS-EW and RiStWag),
- DWA advisory leaflets and worksheets (DWA - German association for water management, waste and wastewater),
- BWK leaflets (German association of engineers for water management, waste management and land improvement).

3.4. Law in the Republic of Switzerland

Although in the heart of Europe, Switzerland is not an EU member. For that reason Switzerland is not obligated to implement the regulations and views from EU Water Framework Directive. But Switzerland's legal system also requires the implementation of numerous provisions and sets objectives for protection and management of waters. While the WFD is based on planning periods with specified targets, the Swiss legislation formulates binding requirements including a set of national limits which must be met at all times [[12]; 28.04.2012.].

If we are looking from hydrogeological point of view Switzerland is extremely important when it comes to European water management because a large number of important European waters flows through it or is in large part on its territory. For these reasons, the Swiss management of those waters on which it shares the regulatory obligation to neighboring countries, is carried out in accordance to an integrated and uniform laws based on the principles of sharing responsibilities and management of the river basins that we already mentioned in a section about EU laws. So Switzerland is a member of many different international commissions:

- international commission of the Rhine River Basin[31],
- international commission of the Lakes of Constance[32], Geneva[33], Lugano[34] and the Lago Maggiore[35].

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[31] countries involved are Switzerland, France, Germany, Netherlands and only partially Italy, Austria, Liechtenstein, Luxembourg, and Belgium.
[32] countries involved are Germany, Switzerland and Austria.
[33] countries involved are Switzerland and France.
[34] countries involved are Switzerland and Italy.
[35] countries involved are Switzerland and Italy.

Because all of its neighboring countries are member states of EU and they have all accepted Water Framework Directive as a major Directive for water issues, Switzerland collaborating with them in order to achieve water protection goals in some level indirectly accepts certain principles determined by the Water Framework Directive.

The most important legal documents when it comes to water protection and management in Switzerland are:

- Federal Water Protection Law or more commonly the Water Protection Act,
- Federal Law on Hydraulic Engineering,
- Federal Law on Water Use.

The major Swiss legislation for water protection and management on national level is contained in the Water Protection Act and the Water Protection Ordinance adopted under the Act. According to Article 1 of the Water Protection Act its purpose is to protect waters against harmful effects of any kind. In particular the Water Protection Act main goals are to:

- maintain the health of persons, animals and plants,
- guarantee the supply and economic use of drinking water and water required for other purposes,
- maintain the natural biotopes of indigenous fauna and flora,
- maintain waters suitable to sustain natural fish populations,
- maintain waters as an element of the landscape,
- ensure the irrigation of agricultural land,
- permit the use of waters for leisure purposes,
- ensure the natural functioning of the hydrological cycle.

Generally it contains provisions on overall as well as use-related measures for protecting and managing waters and it should be applied to all surface and subterranean waters[36]. It establishes qualitative and quantitative goals for the protection of the physical and chemical quality of water. As the theme of my work are polluted stormwaters, in article 6 of the same Act it is determined that it is prohibited to engage or infiltrate into a body of water any substances which may pollute such water or to store or spread such substances (potential pollutants) outside such bodies of water if there is a justified risk of water pollution.

As the part of the Water Protection Act the Water Protection Ordinance defines the ecological targets and water quality requirements for surface and groundwaters, which must be met at all times. In chapter 2, section 1 of this Ordinance it is defined that the authorities should determine differences between polluted and non-polluted waste water assessing the water body based on:

- the type, the amount, the characteristics and the temporal occurrence of substances which are contained in waste water and which can pollute bodies of water,
- the condition of a body of water into which waste water is discharged.

The Ordinance also defines standard quality values of indicators for waste waters based on maximum concentrations of individual potential pollutants that can occur in it. Quality of stormwaters from highways also falls under this regulations as the specific legislation considering this problem still doesn't exist.

[36] Groundwater (including spring water), aquifer, lower and upper confining bed

Although Switzerland is not a member of any Alliance it is still bound to adopt international recommendations due to integral and sustainable regulation and management of waters. One of these legislatives is the Protocol on Water and Health. It is an international agreement on the promotion of health through improved water management and control of water-related disease (Swiss Confederation, no year). The Protocol doesn't specify any technical standards, but a strategy for strengthening cooperation between the various authorities concerned with water management at national and local level and also across international boundaries.

The areas of interest mentioned in the Protocol are managed in Switzerland primarily by two federal authorities:

- the Federal Office of Public Health (FOPH)
- and the Federal Office for the Environment (FOEN).

3.5. Law in the Republic of Croatia

In the year 2013 Croatia will become a full member of the European Union and will be one of the member states. Thereby the implementation of European legislation into Croatian legislation is already fully underway and Croatia plans, though not yet an official member, to honor all deadlines set by the European legislative bodies for the realization of certain integral goals. For the purpose of analysis and in accordance with this work, only legislation relating to waters will be addressed in this section.

Croatia is facing many challenges in achieving the goals set by the European Union, especially when it comes to the field of environmental protection. According to the report of the European Commission on the Croatian progress in 2010 (2010), overall good progress was made regard to alignment and implementation of legislation. The biggest progress has been made in the areas of measuring air quality, industrial pollution control, risk management, climate change and especially in the field of water quality. It is necessary to complete the alignment of legislation on water quality and to a certain extent those related to climate change. It is still necessary to improve enforcement of environmental impact assessment and strategic environmental impact assessment, to improve access to information and justice in environmental issues and cooperation with non-governmental organizations active in the field of environment.

The most important legal frameworks in the field of water in the Republic of Croatia are:

- the Environmental Protection Act (OG[37] 110/07),
- the Water Act (OG 130/11)[38].

[37] Official Gazette (in Croatian Narodne Novine) – NN 110/07
[38] still active are also versions OG 153/09 as well as OG 63/11

In accordance with the corresponding text the Environmental Protection Act regulates:

- the principles of environmental protection and sustainable development,
- protection of environmental components and the environment from the effects of load,
- the subjects of environmental protection,
- documents of sustainable development and environmental protection,
- environmental protection instruments,
- environmental monitoring,
- responsibility for damage, etc.

Especially important, when it comes to water preservation, is the article 23 of the Environmental Protection Act (Article 23 - Water protection). Under the term of water protection, measures to protect water are included as well as the measures to improve water quality to avoid and/or minimize damaging effects on human health, freshwater ecosystems, quality of life and the environment. Protecting water is extremely important due to sustainable development and protection of public and enviromental health.

The single most important legal framework regarding water laws in Croatia, is the Water Act. It is also the most important law when it comes to implementation of EU Water Framework Directive (EU water laws) to the Croatian regulation system. The Water Act regulates the legal status of water, water resources and water structures, managing water quality and quantity, protection from flooding, detailed melioration drainage and irrigation, activities of public water supply and public sewage systems, special activities for water management, the institutional structure of these activities and other issues related to water and water well (OG 130/11).

According to article 2 of OG 130/11 the provisions of this Act relate to:

- surface and groundwater,
- coastal waters in terms of their chemical and ecological status,
- waters of the territorial sea in terms of their chemical state in relation to findings of drinking water,
- mineral and thermal waters, except mineral and geothermal waters from which mineral resources can be gained or accumulated heat can be used for energy purposes what is regulated by the Mining Act (OG 49/11).

Based on the provisions of the Water Act the Water Management Strategy (OG 91/08) was created and accepted by the Croatian Parliament in year 2008. The proposal draft of the Strategy was given by Croatian Waters[39]. The Water Management Strategy represents a long-term planning document which sets out the vision, mission, goals and tasks of state policy in water management and it is based on scientific studies, continuous monitoring of the water and its use, respect for specific water problems of each river basin district and the whole environment in general. The main objective of the strategy is to achieve an integrated and coordinated water regime in each of the four catchment areas[40] in which Croatia is divided to:

- Sava river catchment area,
- catchment area of the Drava and the Danube rivers,
- Dalmatian catchment area,
- water area of the Istrian and Primorje catchment areas.

[39] a legal entity for water management in the Republic of Croatia
[40] geologically divided water regions in Croatia

Upon coming into effect of the Water Act there has been formation of new bylaws and in accordance with the rules from WFD. Bylaws are divided into regulations, plans, decisions, agreements and ordinances.

Unfortunately, in Croatia the management of stormwaters on highways is not specially treated by legal frameworks. In the Water Act there are no regulations or any suggestions on how to deal with this problem. Regulations as well as realization techniques and monitoring principles can only be found in some ordinances and regulations which are not legally binding.

Also, despite the specific and highly complicated structure of the underground geology, which would be extremely vulnerable if there was unregulated contamination, this aspect of the legislation is not as regulated and controlled as it should be. Currently, groundwater quality is controlled only by the ordinance of sanitary drinking water because about 90% of water for water supply of Croatia comes from groundwater wells and springs. Only a list of parameters and maximum allowable values of indicators was given in the ordinance, but not the ways of protection and prevention in order to prevent contamination. This means that when it comes to full protection of groundwater in Croatia, regulations and methods from European Union Water Framework Directive should be applied.

Some other important ordinances and regulations related to water protection and to above mentioned acts are:

- Ordinance on sanitary safety of drinking water (OG 48/04),
- Ordinance on limit values of hazardous and other substances in waste water (OG 94/08),
- Ordinance on emission limit values for waste water (OG 153/09).

3.6. Summary

When we look closely into different legislations we can see importance of projects such as MASH where the knowledge from more developed countries can be transferred to those less developed.

After comparison we can see that while in Croatia management of stormwaters from highways is based on legally non-binding guidelines in other countries we have strict legal frameworks addressing this issues.

In the USA the stormwaters are subjected to water quality standards defined with the CWA as the major water-relating law. CWA primarily gives boundaries and 'instruments' for identifying nonpoint sources which cause pollution and processes for identifying best management practices and measures for dealing with specific problems and identifies and describes State and local programs for controlling pollution from nonpoint sources. As it is hard to fully clean polluted waters (technically and financially) legal limits of contaminants for potential regulation are given from EPA and in the SDWA.

In Europe, on the other hand, the major legislation is the Water Framework Directive which provides legal norms and basic principles that have to be met by the member states of EU. If we compare it to the situation in the USA we can see that the concept of distribution of responsibilities is almost the same. In both cases there is a basic legislation which must be satisfied and then there are State (in EU member states) or local (f.e. in Germany federal states) legislations dealing with specific issues for each region, but with the obligation that the conditions of primary legislation are met. Although WFD is a capital law it leaves to its member states enough room for improvement of the problems which aren't either specifically or well elaborated in the basic legislation. EU law is not obligatory in all European countries but, and because of the river basin management principle, it has found a way into different legislations because of the need for shared and unified management of water resources.

Germany is a good example on how the distribution of responsibilities in the practice should look like. Although the European and national legislative issues related to management of stormwater from highway are not studied in detail, detailed recommendations and obligations are issued at the federal state level and in this way each region determines its own unique provisions that are legally binding for that specific region. There are many ordinances, regulations, etc. which address this issues and can be used as a solid basis for recommendations and analysis for less developed countries.

4. CROATIA AND ITS FUTURE DEVELOPMENT

Croatia is a country located in southeastern Europe, in the part known as the Balkans (figure 15). Because of its cultural diversity and historical impacts as well as geographical position, we can say that Croatia is defined by many different influences and can be characterized as Mediterranean, Central European and Southeastern European country. Croatia shares its western border with Slovenia, northern border with Hungary, eastern border with Serbia and Bosnia and Herzegovina and southern border with Montenegro. Croatia also has a sea border with Italy in the Adriatic Sea. The Adriatic Sea is important geographical characteristic of Croatia and it is a part of the bigger Mediterranean Sea. Croatia is entitled to Adriatic Sea along with Italy, Slovenia, Albania, Montenegro and Bosnia and Herzegovina while the biggest part belongs to Croatia and Italy.

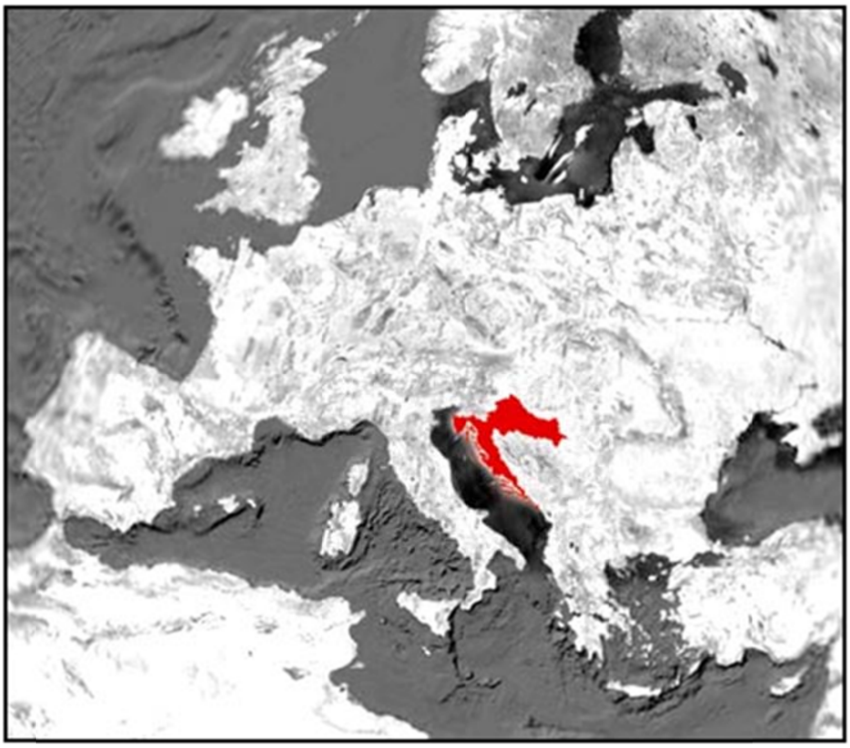


Figure 15: Geographical position of Croatia on map of Europe [[21]; 01.06.2012.]

According to Croatian Bureau of Statistics (2011), Croatia has a total of 4290612 inhabitants which is in the range of countries such as Denmark, Norway or Finland. Its surface area is around 56542 square kilometers (km^2) and it is for example as big as Netherlands, Denmark or Switzerland. In this terms it can be said that among the European countries Croatia is medium sized and rarely populated. In mentioned area the area of territorial sea, which is 31067 km^2, is not included.

According to Croatian homepage [[21]; 01.06.2012.], geographically, Croatian territory is divided into 3 different natural geographic regions:

- lowland region, also called Pannonian region which covers 55% of the territory and 66% of the population,
- coastal region, also known as Adriatic region which covers 31% of the territory and 31% of the population, and
- mountain region which covers 14% of the territory and only 3% of the population.

In the economical and functional sense Croatia can be divided in 4 macro regions such as: Zagreb (central Croatia), Osijek (eastern Croatia), Rijeka (north Croatian coast) and Split macro region (southern Croatian coast).

Because of its relief characteristics, Croatia is considered to be mainly lowland area. Main reason for this is more than 50% of its territory that lies below 200 meters above the sea and the fact that there is no mountain area higher than 2000 meters above the sea. Genarally speaking, beside islands, lowest lying areas in Croatia are its northwestern (Istria) and eastern (Slavonia) part.

The 'mountain' parts of Croatia, with the highest peaks and areas are lying in the transition area, from continental to coastal Croatia or directly by the sea, spreading parallel with coastal line. Highest mountains in Croatia are:

- Ucka,
- Velebit,
- Risnjak,
- Great Chapel,
- Pljesivica,
- Dinara.

When it comes to the climate properties, Croatia has favorable, moderate climate as it is located in the northern temperate climate zone [[21]; 01.06.2012.]. Due to significant temperature and weather differences in different parts throughout the year all the four seasons can be distinguished. The climate of Croatia is mostly influenced by the relationship of land and sea, and also different geographic structures and elevations which define different climatic regions where the most represented one is moderately rainy climate region. Warm humid climate can be found in continental Croatia while the coast and islands have Mediterranean climate. Only the highest mountain areas have snow-climate. Main Croatian climate zones are presented in figure 16.

Figure 16: Croatian climate zones [[22]; 02.06.2012.]

In Croatia the coldest month is January with an average temperature ranging from -2°C (mountains) to 5°C (low land areas - coast) while the hottest one is July with average temperature ranging from 15°C (mountains) to 24°C (low land areas - coast). Croatia has an annual precipitation average between 800 and 1000 mm (in the previous chapter, chapter 2, it was determined as 864 mm) which gives a general picture of Croatia as the moderately humid country favorable for agricultural production. Croatian inland is a part with minimum average precipitations. With an average of 2,600 hours per year the Adriatic coast is one of the sunniest in the Mediterranean and the city with most sunny hours per year is Hvar.

When it comes to geology structures, all three major groups of rocks are represented in Croatia:

- sedimentary rocks[41] (forming about 95% of Croatian relief) such as marbles, schists and gneisses,
- igneous (volcanic) rocks[42] (forming about 1% of Croatian relief) such as limestone,dolomite and clastics,
- metamorphic rocks[43] (forming 2-4% of Croatian relief) such as granite and andesite.

The special geological and geomorphological phenomenon specific for Croatia is called karst. It is a geomorphological shape that is a product of force of water on the limestone bases and there are different forms of it such as: sinkholes, estavelles, caves, etc. More about karst in Croatia is mentioned in future text.

In the eastern, central and western part of the Croatia black soils, brown acidic soils, brown marl soils, wetlands, river valleys and alluvial soils are present. Along the coast linear red and brown soils on limestones and dolomites mixed with the rocky are mostly present. Croatia is one of the few countries with a rich and diverse forest ecosystem that covers 37% of its total territory and the highest percentage of forested area is in 'mountain' part of Croatia. Most of Croatian forests are deciduous forests, followed by conifers and mixed forests. In coastal regions of Croatia degraded forest cover is characteristic and the largest part of vegetation are bushes, shrubs and rocks.

[41] Sedimentary rocks are formed by deposition of a large, loose material (sand, gravel, ..), or bigger amounts of organogenic materials

[42] Igneous rocks are formed by surface eruptions and outbursts of lava or internal cooling of molten minerals

[43] Metamorphic rocks are formed by chemical changes to the original rock

Croatia is a country with an above average amount of water per capita. Of the total available water big part are groundwaters with satisfactory quality. This effect is due to limited development, low population density and also the rational management of water resources.

Special wealth of Croatia are mineral and thermal spring waters. Thermal waters are well known for their health, energy and economic potential and they are available in big quantities and are well spaced.

4.1. Karst in Croatia

Karst is an area composed of a special surface and underground relief. It consists mainly of limestone and dolomite rocks which are highly soluble in contact with water. If we take into account continuous chemical action of water on the structure, which makes occurrence of cracks and underground channels possible, it is clear that the concentrated flow of water appears in these situations and along with it distinct mechanical actions which cause further devastation of the present structures. That is why it can be said that karst has highly developed surface and underground hydrographic network where water can achieve significant velocity.

According to Rubinic (no year) and from Bonacci (1987) soluble rocks located at or near the surface are inherent to karst. The process of karstification is the result of physical and chemical action of water on the dissolution and removal of dissolved substances in the rock massif.

According to Fleury (2009), there are many different forms (karst landscapes) in which karst can be found, such as:

- sinkholes (dolines),
- caves and caverns,
- springs,
- poljes,
- karst valleys,
- swallow holes,
- residual hills,
- cockpit karst,
- cone and tower karst.

Karst is a widely distributed phenomenon which covers about 20% of the world's land surface and it may be found at various locations. In Europe, the most important karst distributing areas are the Dinarides, the Helenides, the Apennines, the Pyrenees, the Alps, the Crimea and the Carpathian-Balkanides. Croatian karst belongs entirely to the group of Dinaric karst.

Dinaric karst is known worldwide as the classic type of karst, i.e. locus tipicus[44]. According to Rubinic (no year), if we look into its morphological and hydrogeological characteristics, Dinaric karst in Croatia is divided into:

- Adriatic region (islands and coastal areas),
- area of high karst,
- the inner area.

Due to different interpretations and definitions of karst and its borders, there are many opposite theories[45] on percentage of Croatian mainland territory that is considered to be of karst origin. We can see differently given boundaries of karst in Croatia in figure 17. Given its characteristics, it is impossible to accurately establish the boundaries. The most recent researches point out that it is around 52 percent [[24]; 04.06.2012.] and it's one of the biggest values in the world.

If we look at Croatian territory from hydrogeological point of view, we can see that it is divided into 2 big basins:

- Black sea basin (Danube basin),
- and Adriatic basin.

[44] latin for the geographical place of collection where a holotype or type specimen of a nominal species or subspecies was first found and described - english: type locality

[45] Roglic - 45%; Rogic - 45% but different border line; Report on the state of the environment in the Republic of Croatia - 52% to 54%; Ministry of Environment and Physical Planning of Croatia - 54% to 56%; Pejnovic - 48,9%

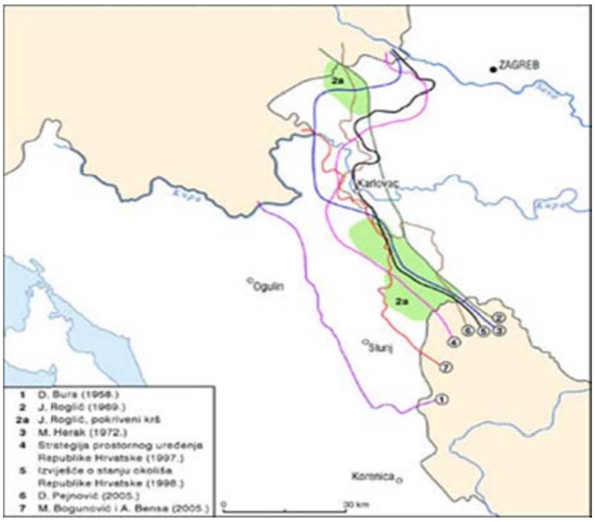


Figure 17: Theorethical boundaries of karstic region [[24]; 04.06.2012.]

The border line (watershed) of Croatian basins takes place in part of Croatia called Gorski kotar. The percentage of Croatian mainland territory falling under the Adriatic basin is around 32%. This is important because only small part of Black sea basin matches karstic region of Croatia while the Adriatic basin falls entirely under karstic territory. We can see that from comparison of figures 17 and 18. On figure 18 green colour represents Black sea basin while blue represents Adriatic one.

Figure 18: Border line between Adriatic and Black sea basins (Loncar, 2010)

This fact is important when it comes to treatment of stormwaters from highways because of high water pollution potential that this areas have. Because of the network of interconnected tunnels and underground channels possible contamination can be transported very quickly from one place to another which makes karst extremely sensitive when it comes to pollution of groundwater. That same groundwater in Croatia makes a large part of the potential water supply and any pollution can be followed by severe consequences. When it comes to pollution, the main characteristic of karst areas is extremely small level of autopurification and almost entirely unknown network system of underground structures which means that contamination can be easily and uncontrollably transferred to various distant places. In some cases underground retention of stormwater flow occurs. In next big storm event this water gets mixed with new stormwater and then we have underground flows with quite big contamination level.

There are records in Croatia that in some cases, losses of entire water sources, and due to pollution that occurred in some moment, happened. An example of this is found in the work of Rubinic (no year) where he states that the loss of Pula wells, used to supply the Pula area, occurred. Soil retention and removal conditions of the contamination are dependent on its origin.

Generally speaking, the problem of pollution of water supply sources in Croatia is solved by establishing a protection zones of aquifers. This issue will be discussed later on in this chapter..

4.2. Transportation infrastructure and future development

Although the road system in Croatia is developing rapidly and with high quality, it still needs to reach level of those in the developed countries of Europe. On the road construction in Croatia in the last 15 years a huge step forward has been made.

The project of road system development, that should be fully implemented in the next few years (proposed end of construction is year 2020), was approved in the strategic documents of the Government and Parliament and is strongly supported by the Croatian public. Based on what has been done until now it can be concluded that the basic components of the network are completed.

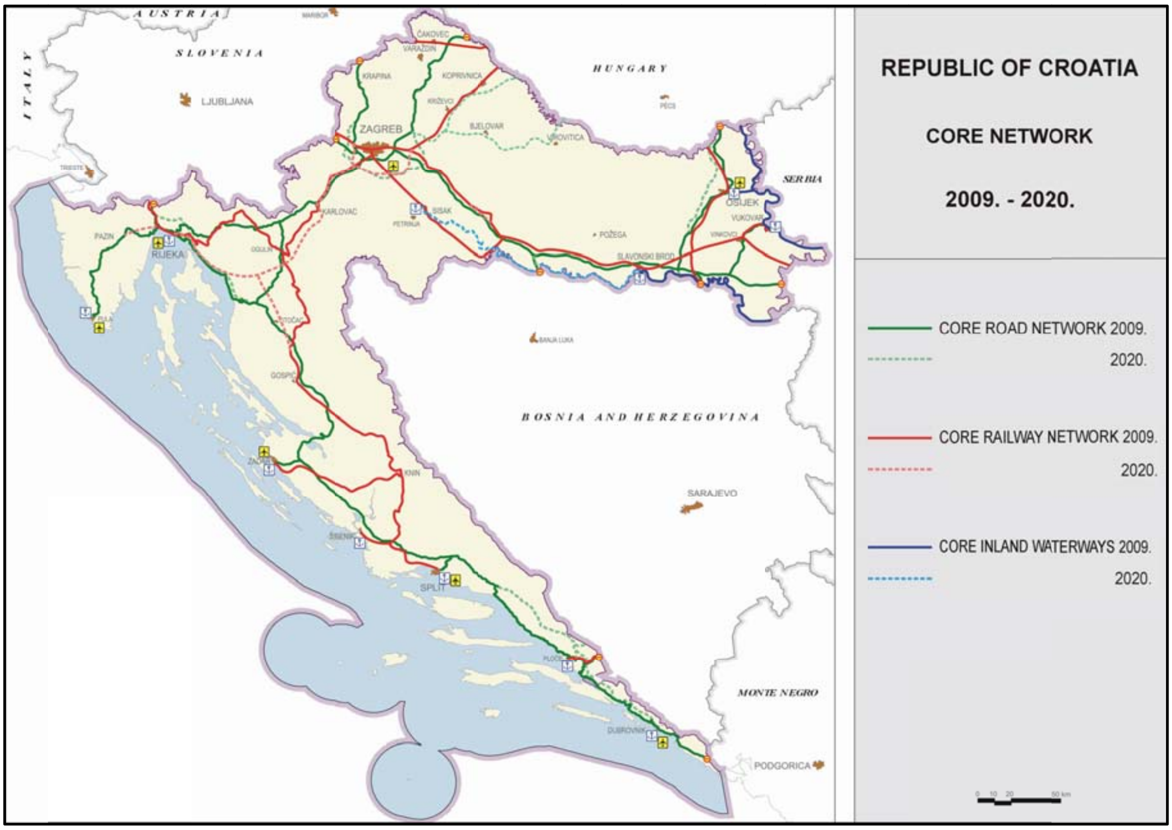


Figure 19: Existing and transportation networks planed by the end of 2020 [[23]; 03.06.2012.]

Although construction of Croatian motorway network was recognized as a strategic requirement for economic development of Croatia, until 1998 mainly studies and projects were produced and there wasn't a lot of construction going on. But these documents gave the basis later on and they enabled the rapid development in future years.

Motorway network in Croatia is determined by the Croatian Physical Planning Strategy from 1997 and the Transport Development Strategy for Croatian Republic from 1999. According to Crnjak and Puz (2007) important notice is that the highways are developed in accordance to the ongoing changes in traffic demands by actions such as:

- build of a new rest stops and interchanges,
- increasing capacity by adding another lane.

The geographical shape and position of Croatia, where it is connected to the northern lowland routes on one side and the shore of the Adriatic Sea on the other, clearly indicates the vital importance of transportation infrastructure for its development. It also indicates the need for land and sea international connections of other European countries over Croatian territory.

Although Croatia has inherited most of its traditional transportation infrastructure from the former 'regimes'[46], it was generally not enough to meet the needs of the modern transport infrastructure. The new requirements were defined and some of them were:

- the necessity of transport connectivity and territorial integration of the Republic of Croatia,
- the need to connect through a modern and secure infrastructure,
- the need to achieve inter-operability of Croatian transport system with transport systems of our neighbor states (both EU and non-EU states).

[46] the Austrian-Hungarian monarchy and two Yugoslavian states (from year 1918 to 1941 and from 1945 to 1990)

The favorable geographical position allows the development of the Croatian transport infrastructure and activities as one of the most important factors of the overall economic and social development.

Croatian territory is extremely traffic in terms of transit. There are three Pan European Corridors (V, VII And X)[47] going through the country. Traffic and transportation development in general is not only internal need of the Republic of Croatia, but also one of its potential comparative advantages. The choice of multimodal Pan-European Corridors through Croatian territory is proving the strategic importance of the Croatian position in the European transport framework. If a fact that tourism is one of the main propulsive sectors of Croatian economy is added to all above mentioned facts, it can be said that:

- transport infrastructure has a potential to significantly affect the competitiveness of Croatian tourism,
- a large part of goods and services required for the tourist offers also comes through transport infrastructure.

When it comes to terms of managing highways, Croatian Motorways is a limited liability company for managing, building and maintaining highways, which started functioning in 2001 as one of two legal successor Croatian Road Department. The company is wholly owned by the Croatian. Croatian Motorways carry out their activities according to the four-year program of construction and maintenance of roads by the Government of Croatia.

[47] Vb: Rijeka - Zagreb - Varazdin - Budapest; Vc: Ploce - Sarajevo - Osijek - Budapest; X: Salzburg - Villach - Ljubljana - Zagreb - Belgrade - Skopje - Thessaloniki; Xa: Graz - Maribor - Zagreb;
VII: Danube (and the Save river waterway)

4.3. Highways system in numbers

Numeric facts given in this section are taken over and modified from the work 'Key Numbers 2011' made by Croatian Association of Toll Motorways Concessionaires (2012).

Systematic expansion of Croatian highways occurred in the early years of 21st century, where in 10 years almost 700 km of highways were built. Development was rapidly slowed with the arrival of the global economic crisis which affected Croatian economy in 2009. From about 1500 km of planned motorways, 1250,7 km is opened for traffic at the moment. The rest should be built by 2020, and this will depend largely on the development of the global economic situation. Work slowdown is partly caused by the fact that the funds used to finance the construction are diverted to the maintenance of existing structures. Declining highways development trend is continuing also in 2012 where only 1,5 km of new sections will be ready for opening.

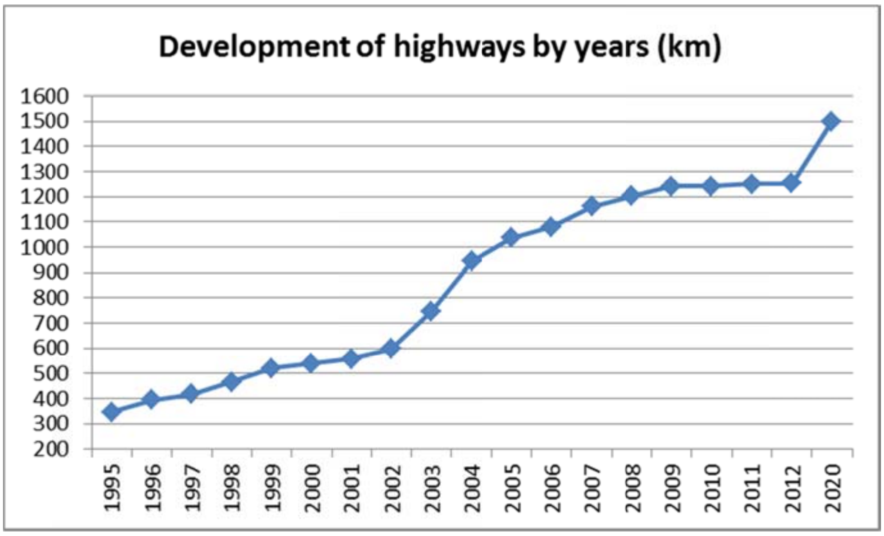


Figure 20: Planed development of Croatian highways (modified according to Croatian Association of Toll Motorways Concessionaires, 2012)

Planed sections of highway system should be completed if Croatia wants to achieve its full potential as a transit and tourism oriented country. Unfortunately, from the current situation in Croatian economy it does not look like it will be possible to comply the given deadline. The reason is that in this moment investments for road development are limited. Also progress of infrastructure is causing growth of requirements in terms of its proper maintenance which means that more money must be provided to cover the costs of maintenance and reconstruction of existing facilities. In such circumstances, the given deadline seems rather ambitious.

If we consider current trend of slower development and the state of national and European economy and if as a base for projection of development potential we take the period since 2008 conclusively with presumed development in 2012, we can conclude that the completion of a full profile of Croatian highway network can be expected not before year 2025. This is assuming that in 5 to 7 years there will come to a gradual exit from the critical economic situation. If not, the deadline will probably have to be extended for even more time.

4.4. Sanitary protection zones

There are no strict regulations in Croatian laws just considering stormwater management. Disposal of all waters needs to be regulated according to safety regulations for drinking water. This terms are already closely explained in third chapter.

Ensuring the quality of drinking water is primarily achieved by removing potential dangerous situations, i.e. causes of pollution. The main tool in the fight to preserve required quality of water is determination of sanitary protection zones of water sources used to supply the population. Each zone of protection has certain restrictions that are based on numerous physical and chemical parameters relevant for a particular procedure. Sanitary protection zones are determined on the basis of researches by numerous experts, and their quality and adequacy of implementation are confirmed by the Croatian Waters as a leading organization for issues of water management in Croatia.

According to Ordinance on the conditions for establishing water protection zones (OG 61/2011) from 2011, water research works that are used as the basis for setting limits and conditions of the protection zones are:

- geological features and hydrogeological and hydrologic relations of inflow areas,
- size, boundaries and yield of the aquifer,
- type of aquifer according to porosity (porosity of the fine grained soils, cracking and the cracking-cavernous porosity),
- cover thickness and permeability of the aquifer sediments,
- the supply mode for the aquifer,
- flow path into reservoir or lake,
- velocity of groundwater flow towards the source,
- purification capacity of the cover sediments and the aquifers,

- water quality
- analysis of natural systems and the overall impact of human activities.

Based on these data a draft elaborate of sanitary protection is made, and it has to be approved by the Croatian Waters. If done studies are sufficient enough, determination of zones of sanitary protection can be conducted, but if it is not the case, additional research must be carried out. There are some certain recommendations for determining protection zones but the final results arise primarily from local conditions.

According to local conditions, different protection zones are determined for 4 specific regions of water supply:

- groundwater sources in fine grained porosity soils (table 8),
- groundwater sources in cracking and cracking-cavernous porosity soils (table 9),
- surface water sources from reservoirs and lakes (table 10),
- surface water sources from open watercourses (table 11).

Table 8: Protection zones for groundwater sources in fine grained porosity soils (modified according to OG 61/2011)

Protection zone	Description	Boundary conditions	Baned actions (important for stormwater management)
III	Restrictions and monitoring zone	Area outside zone II boundaries and to the calculated border of underground supply area for the minimum residence time of water for a period of 5 to 25[48] years of the horizontal flow, before the entrance of water to water catchment facilities	Construction of roads, airports, parking lots and other transportation and manipulative areas without controlled drainage and adequate treatment of polluted stormwaters before discharge into the natural receiver; discharge of untreated wastewater
II	Strict limitations and monitoring zone	Area outside zone I limits and to the line of where underground water has a minimum retention time in the underground of 50 days before entering water catchment facilities	Discharge of treated and untreated waste water from roads
I	Strict protection regime and monitoring zone	Area at least 10 m distanced from water catchment facilities on all sides and sicured by a fence high enough to prevent entry of unauthorized persons	All activities except those related to the catchment, conditioning and transport of water in the water supply system, are prohibited

As it is shown in table 8, there are 3 protection zones present in fine grained porosity soils. In some cases only zones I and III are established due to conditions in catchment area where zone II is not needed. These protection zones are characteristic for big part of central and entire eastern Croatia and so far in practice they have proved to be sufficient enough.

[48] it depends on maximum water resources capacity in terms of abstraction dynamics (groups are < 20 l/s; 20 - 100 l/s; > 100 l/s)

Table 9: Protection zones for groundwater sources in cracking and cracking-cavernous porosity soils (modified according to OG 61/2011)

Protection zone	Description	Boundary conditions	Baned actions (important for stormwater management)
IV	Restrictions zone	Area outside zone III with potential flow in terms of high water, to water sources in the period from 10 to 50 days; areas of underground water velocity < 1 cm/s	Construction of roads, parking lots and airports without drainage devices or oil/grease separators and appropriate treatment system for contaminated stormwater; discharge of untreated wastewater
III	Restrictions and monitoring zone	Area outside zone II and to the border with a potential flow of underground water to water sources in the period of 1-10 days in conditions of high water; areas from which apparent groundwater flow velocity of 1-3 cm/s are determined; an area that covers most of the catchment	In the terms of stormwater management same as for protection zone IV
II	Strict limitations and monitoring zone	Includes major underground drainage routes in direct catchment area of water sources, with possible underground flow to water sources of up to 24 hours; areas where apparent velocity of groundwater flow in high water conditions greater than 3,0 cm/s is determined; inner part of the classical inflow areas	Discharge of treated and untreated waste water from roads; construction of all other facilities that could threaten groundwater quality
I	Strict protection regime and monitoring zone	Direct alluvial area of water sources, the source aquifer, catchment facility, pumping stations, water conditioning devices, buildings for safeguarding of artificial aquifer supplies, regardless of the distance from the water intakes; in large flood areas on the steep and inaccessible terrain, zone I can be divided into IA and IB	All activities except those related to the catchment, conditioning and transport of water in the water supply system, are prohibited

In table 9 we can see protection zones for cracking and cracking-cavernous porosity soils (karst areas). Restrictions for these areas are stricter referring to conditions that occur (already mentioned in previous section). There are 4 protection zones for these areas, while in some situations zone I can even be divided into zones IA and IB. Also, if in the mountainous areas beyond the borders of zones are areas of collection, retention and runoff of water (to the source), these areas may be identified as special water supply reservations. Passive safety measures for zones IV, III and II can be applied if necessary.

Table 10: Protection zones for surface water sources from reservoirs and lakes (modified according to OG 61/2011)

Protection zone	Description	Boundary conditions	Baned actions (important for stormwater management)
III	Restrictions and monitoring zone	Reservoirs and lakes in which water flows exclusively by the land surfaceand not through the river or stream and it includes area outside zone II and to the outer limits of the reservoirs or lakes basin	Construction of roads without drainage devices or oil/grease separators and appropriate treatment system for contaminated stormwater; discharge of untreated wastewater
II	Strict limitations and monitoring zone	A belt of at least 100 meters width on each side of the inflow measured from the outer border of zone I, and it extends along the inflow border to reservoirs or lakes sub-basin; also a belt of 100 meters along the reservoir or lake measured from the outer boundaries of zone I	In the terms of stormwater management same as for protection zone III; construction of all other facilities that could threaten groundwater quality
I	Strict protection regime and monitoring zone	Includes accumulation or lake, dam, water catchment facility, pumping station, water conditioning device, facilities for safeguarding of source, protective settling tanks at the mouth of inlet and buffer zone along the lake or reservoir with a width of 10 m from the edge of water at the highest water level	Execution of works, construction and performance of economic and other activities necessary for the abstraction, conditioning and transport of water in the water supply system; public transport of vehicles and pedestrians

In table 10 protection areas for reservoirs and lakes are shown. Although only small percentage of supplying waters are being used from these sources (around 10% along with open watercourses) there are still severe restrictions present in order to maintain the necessary water quality. Restrictions for each protection area are roughly equal to those for groundwater sources in fine grained porosity soils.

When it comes to determination of protection areas for surface water sources from open watercourses only sanitary protection zone I is determined. These systems are less represented when it comes to water supplying because of lower quality of water, i.e. because they require application of purification systems, which considerably increase water supply costs. In table 11 we can see protection area for open watercourses and its main characteristics.

Table 11: Protection zones for surface water sources from open watercourses (modified according to OG 61/2011)

Protection zone	Boundary conditions	Baned actions (important for stormwater management)
I	Includes area of direct water sources, stream banks and river bed next to the water catchment, pumping stations, water conditioning device, buildings for preservation of source and the opposite side in the width of 10 m from the edge of river bed if the river bed is narrower than 20 m at low water; at least 10 m away from the water catchment in all directions, and is marked by buoys; boundaries in relation to buildings on the shore above the high water level must be at least 10 m far on all sides from the following structures: catchment facility, pumping station, water conditioning device, facilities for preservation of source and must be fenced with stable fence	Public transport of vehicles and pedestrians

4.5. Current practices for stormwater management - criticism

After literature study (available literature was limited) it can be concluded that although there are certain guidelines for drainage and treatment of stormwaters from highways (and roads in general), there is no binding legislation that would allow the implementation of these safety measures. The major problem is the possibility of free interpretation of certain parts of the legislation which causes unequal quality of constructed systems, sometimes even on the same routes.

Decisions regarding specific issues are mostly the result of subjective opinion of a few responsible people. The reason lies in the fact that a particular situation, is not individually approached, and further research is not conducted to needed extent. Also because of insufficiently regulated system database of previous researches is not available, and it could serve as a basis for initial analysis. In many cases, previous studies are not conducted due to extra costs.

Problem is also resistance of responsible structures when it comes to implementing new legal obligations. For example, very strict restrictions cause their low acceptance, and ultimately poor results, while very mild restrictions allow full acceptance but also extremely poor results. On the other hand, medium strict restrictions lead to a good acceptance and optimal progress. This means that local government has to find the optimal approach to all interest groups in order for general progress.

When it comes to monitoring, often it is not sufficient enough because it is limited to the direct area of the highway and its impact on whole wider area is not taken under consideration. Also the problem of inadequate implementation of the environmental impact studies for each individual project is noticeable.

Performed works often have very poor quality, which is demonstrated during use. In many cases maintenance of performed systems is not conducted properly. When it comes to their monitoring, regular analysis of the whole zone of influence should be done, but due to the reduction of total costs of maintaining the monitoring is done only on parts of the basin which are in direct contact with the highway. In Croatian laws system control is not clearly defined, and that should change with implementation of EU laws. Croatia is on the verge of entering EU and thus began compliance of its laws with EU laws. It will take some time in order for accepted guidelines to really take root in the practice of performing systems for control of stormwater from highways. From this we see a real need for projects such as MASH, where specific education and assistance from developed countries can facilitate this transitional processes for less developed ones.

5. STATE OF THE ART

State of the art represents development level of a certain technology. In this chapter a short insight into technical and natural based treatment facilities will be given and for the USA, Germany, Switzerland and Croatia.

When we talk about treatment of stormwaters from highways we can separate two main types: centralized and decentralized treatment. Due to the nature of stormwater, which appears occasionally and in large amounts, it is hard to apply usual cleaning methods. This is especially expressed when we talk about stormwaters from highways. Under centralized treatments we consider treatments of stormwaters from well controled urban areas which usually means usage of combined wastewater collection systems[49], while under decentralized we consider mainly treatments of stormwaters from non local roads such as highways which are too complicated and in the end too expensive to be connected to urban drainage systems.

In first and second part main characteristics of commonly used techniques (technical and natural) in all the countries of our interest for dealing with polluted stormwaters will be described. Also, display of figures for each technology is going to help with better understanding of specific characteristics. Due to a lack of adequate literature and language barrier, information on natural based systems are based on English based literature, which mainly represents general situations in the USA and Croatia, while technical based systems are based on the information from all the analyzed regions with an emphasis on Germany (based on works of Pfeffermann (2011) and Schmollinger (2012)). In analysis, design rules for systems will not be excessively considered as the main target of this work is to give an insight in their pollutant removal performances and limitations.

[49] includes all wastewaters - domestic wastewater, industrial wastes, and stormwater

Generally speaking, Best Management Practices (BMP) will be described, i.e. general situation referring to frequency of use of certain technologies in the above mentioned countries. Perhaps it would be more precise to say that an emphasis will be placed on the most used types of technology, especially when talking about the technical aspect, because the term Best Management Practice is somewhat awkward due to the subjective perception of certain parameters in the evaluation of different practices. The selection of a treatment system for certain location depends on many aspects, from the characteristics of the location to traffic load of road or catchment area with potential contaminants. Also, a generalized comparison of state of the art will be given so we can get insight to differences and similarities when it comes to treatment methods for stormwaters from highways.

Based on gathered information benchmark of stormwater treatment facilities will be presented in chapter 6 and it will be modified according to different sources. These generalized marks will be used as a recommendation bases for analysis of situation and future development in Croatia (also as a part of chapter 6).

5.1. Natural based treatment facilities

Under natural based facilities we consider all treatment systems which are based on natural settings and which don't alter appearance and main characteristics of environment in which they are used. Natural systems are mainly used for cleaning stormwaters from non local urbanized areas, i.e. highways. Natural treatment systems are capable of producing an effluent quality equal to that of technical treatment systems but the main problem with it is that normally they require a lot of space so they would achieve those goals.

The main characteristics of natural based treatment facilities are:

- simplicity of design and construction; even small building companies can build them and they don't require highly qualified staff for their maintenance operations;
- they are cost-effetive - plants require low building, work and maintenance costs; they require almost no energetic consumption; mechanical devices are not used so it contributes to reducing the maintenance costs;
- they are generally rather efficient for the removal of most of the pollutants; their efficiency highly depends on climatic conditions as it is lower with low temperatures;
- they are very reliable even in extreme operating conditions; they can deal with different and extreme hydraulic conditions and the quantities and types of pollutants.

Systems that we are going to refer below in the text are: Vegetated Buffer Strips (Filter Strips), Grassed Swales (Biofiltration Swale), Extended Detention Ponds, Constructed Wetlands, Wet Ponds, Infiltration Trenches, Infiltration Basins, Sand Filters. These are all individual systems but in more complex situations they can be used as a parts of more complex system due to possibility of combinations and requirements of situation.

5.1.1. Vegetated Buffer Strips (Filter Strips)

Vegetated Buffer Strips (Filter Strips or VBS in the future text) is a term for a slightly inclined terrain around the road sections covered with vegetation through which stormwater flow is continuously discharged (Malus, no year). They can be created in any herbal form, from grasslands to forests, and their task is to accept the uniformly dispersed flows from the roads, reduce their speed and then spread them across its own surface. It stabilizes stream banks and shorelines, and prevents bank erosion and slumping. It also causes stormwater to slow down where it loses much of its erosional force when it passes through the strip of vegetation. Dense vegetation enhances the cleansing of stormwater flow from roads through the processes of retention, plant filtration and infiltration into the soil. Forested and enchanted VBS showed low to moderate (medium) effectiveness in removing pollutants, with a small advantages of forested VBS. Removal of dissolved substances is low, again with better results for forested VBS, due to prolonged retention of water and the effect of plant communities. The example of one VBS is presented in figure 21.

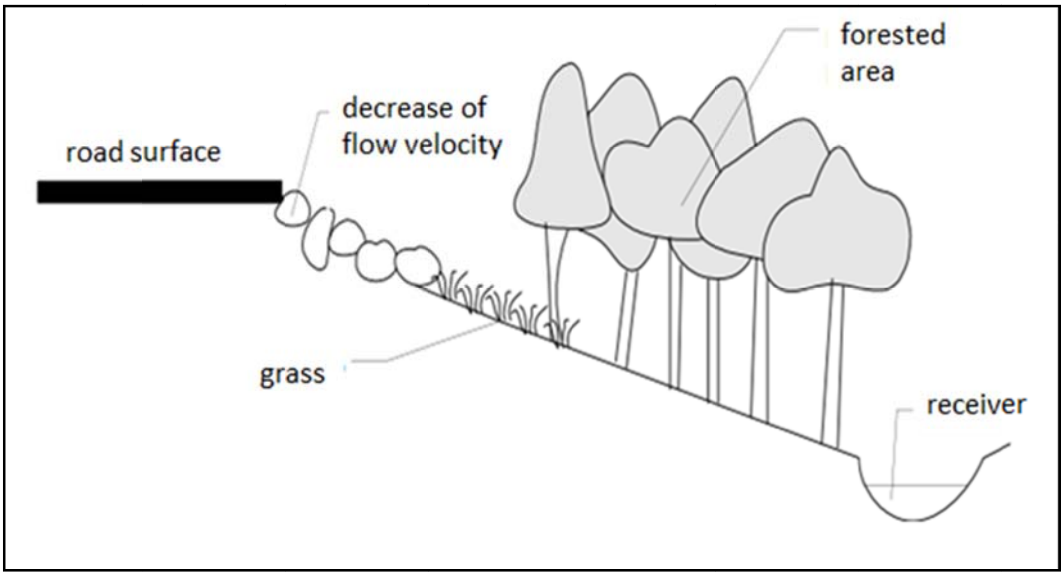


Figure 21: Possible solution of VBS (Malus, no year)

VBS can't be considered as regulation because it can't successfully purify flows with high speeds and keep the larger volumes of water. So we consider it temporary structure. Effective implementation mostly depends on achieving the uniform and not concentrated flow across its surface.

To avoid the formation of concentrated flows, VBS must be:

- equipped with a means for calming the speed and flow distribution,
- covered with a mixture of dense vegetation resistant to erosion,
- aligned in a slightly inclined surfaces.

VBS is usually only one component of the total drainage solution. In such a complex solution VBS is used for sedation of flow, a small reduction of flow volume, it contributes to the aesthetic perception, reduces erosion and creates habitat for wildlife. The vegetation serves as a filter, straining out sediments, nutrients, pesticides and other pollutants before they reach the water body. With good maintenance VBS can last over 20 years (usually from 10 to 20), and their life expectancy significantly reduces the destruction of vegetation and disturbance of flat flow.

VBS should be placed at locations where stormwater flows from the roads drain directly into sensitive receiver. They can be used as the protection for lower placed watercourses, wetlands and lakes or the protection of the outlets from other control structures. The most important elements when choosing a location for VBS are soil type, area and elevation.

Soil permeability must be low, between 0,15 and 4,5 mm/h. Usual soils that fall under this class are clay, loam and sand soil. The presence of organic substances increases the possibility of cleaning. It is best when the groundwater level is within 1 m of the surface layer and when climatic conditions allow rich vegetation throughout most of the year.

The effectiveness of VBS depends mostly on ability to achieve steady flow across the surface and on the size of connected catchment area. To prevent concentrated flows, catchment area connected to a VBS should not be greater than 0,8 hectares (Malus, no year). However, according to Corson (2006), catchment area can even go up to 2 hectares. Longitudinal slope of VBS must be less than 5%, otherwise it leads to explicit erosion effects.

When we talk about efficiency solids and heavy metals are effectively removed at low speed. Removal of dissolved substances occurs when water infiltrates into the ground and when rooted plants use part of it. Generally speaking, system efficiency is a function of length, slope, permeability and flow velocity. Criteria for determining proper dimensions of buffer strips is not well established and recommended designs are highly variable depending on the author. The smallest length of this system should be 6 m but if we talk about effectiveness than optimum length is at least 30 m (and up to 90 m). Width on the other hand depends mostly on slope of land and it should not be less than 15 m with 6 m increase for every slope increase of 5%.

We distinguish two types of VBS: with grass cover and with forest cover. Each of these two types has its own advantages and disadvantages. Although the VBS with forest cover is much more effective for treatment of pollutants, it occupies a large area, which, as an economic factor, in most cases can be a limiting factor. On the other hand, VBS with grass cover is not as effective but takes up less space and in most cases, due to its viability, in combination with another technology.

The biggest advantage of a VBS is that the native plants that do become established are adapted to local conditions and they become a natural part of the specific ecosystem. In this form, they require no maintenance.

5.1.2. Grassed Swale (Biofiltration Swale)

Operating principle of Grassed Swale (GS) is biofiltration. Biofiltration is the simultaneous process of filtration, sedimentation, adsorption and biological degradation of pollutants in stormwater, when it flows through the area covered with vegetation. Biofiltration swale is mutually inclined channel or trench that simultaneously with the cleaning drains stormwater flow from highway. It does not affect the regulation of flow, but drains water to a device intended for that purpose.

According to Malus (no year) general conditions that must be met are:

- swale must be at least 60 m long with maximum base width of 3 m and depth of the water flow must not be greater than 10 cm for 0,5 annual rain,
- longitudinal slope of the swale must be between 1% and 5%,
- swale can be dimensioned as a protective structure at 0,5 annual rain and as a conductor for the peak flow of relevant higher stormwater (f.e. 10 or 50 years) if it is in the linear system of drainage,
- the ideal cross section is trapezoid with a slope no greater than 1:3,
- if the flow is directed into a swale across the opening in the curb, roadway or sidewalk should be slightly higher than the level of a biofilter. Openings in the curb should be at least 30 cm long, to prevent clogging,
- GS has to be overgrown with vegetation to ensure the effectiveness of certain cleaning,
- it is necessary to provide as much contact with vegetation and soil as possible. It is generally necessary to choose a waterproof fine dense grass layer. It is necessary to consult experts in horticulture about types of grass layers we want to use,
- biofiltration swales should not conduct stormwater flows during construction. If it can not be avoided, it is necessary to pre-precipitate the flow,

- before swales overgrowe with vegetation, if possible, stormwater flows have to be turned out of the trench. If it is not possible, inclined surfaces have to be protected with materials for the control of erosion.

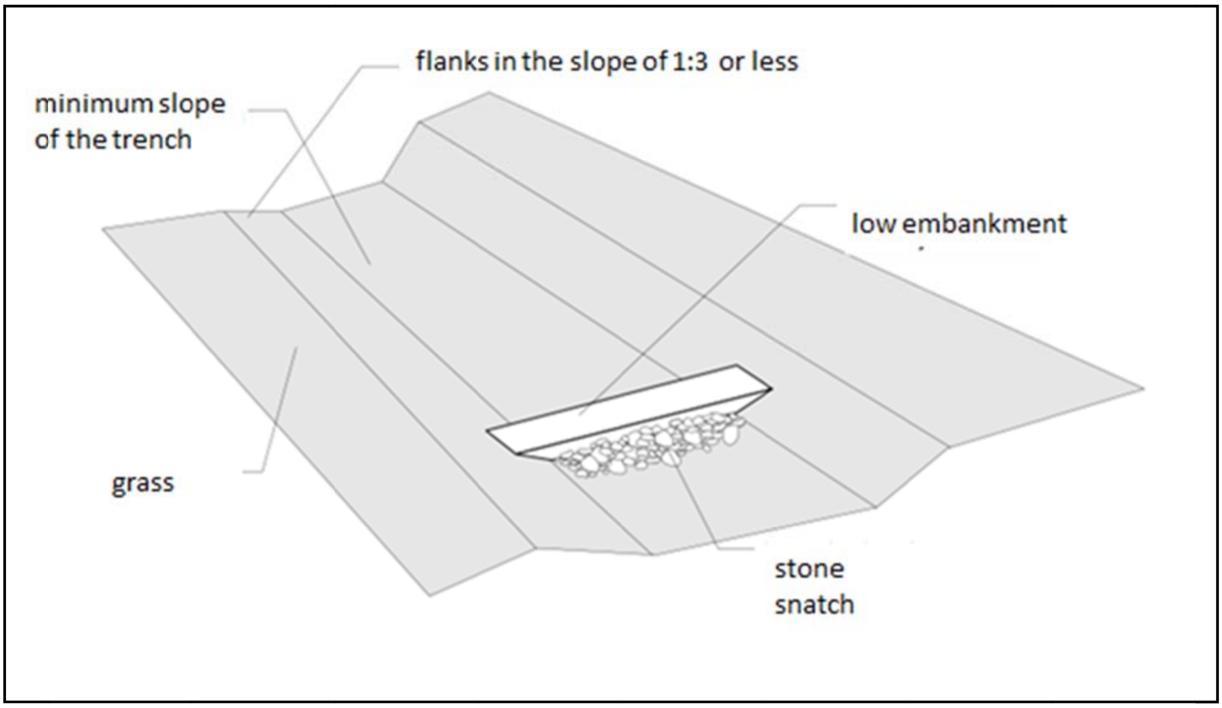


Figure 22: Grassed Swale (Malus, no year)

According to EPA (1997) disadvanteges of this treatment technology are:

- limited removal of fine sediment or dissolved pollutants (f.e. dissolved nutrients),
- require larger land areas than kerb and gutter, and limited access (f.e. car parking),
- adequate sunlight is required, and heavy or prolonged shading should be avoided,
- vegetation needs to be maintained all year,
- reduced effectiveness for concentrated flows and high flow depths,
- generally applicable for slopes of up to 5%,

- high failure rates have been reported-attributed to poor maintenance, poor vegetation cover and difficulties in achieving uniform flow and avoiding channelisation.

Effectiveness of this technology depends on the characteristics of the location. According to Malus (no year) and from Dorman et al. (1988) GS are suitable for mitigating the impact of smaller stormwaters producing low speed and long time of flow. GS is effective with the first inflow because most of the removal of pollutants occurs in the upper part. This technology is extremely effective for removing heavy metals. Effectiveness of GS also depends on the types of planted grasses and their density, size and shape.

The slower the flow in a grass swale, the more pollutants will be removed from stormwater through sedimentation and the straining of stormwater through the vegetative layer. Also, the slower the flow, the more time stormwater has to infiltrate into the ground.

5.1.3. Extended Detention Ponds

Extended Detention Ponds (EDP) remove pollution from stormwater flows and reduce peak flows to the level before the road was built. Pollutants which are removed from stormwater are settleable and floating materials, nutrients, heavy metals and toxic substances. It also protects downstream facilities from erosion and reduces the possibility of flooding (Malus, no year). They can be built in few different forms such as:

- an embankment enclosed cassette,
- excavated lagoons,
- tanks.

One of the main characteristics of EDP (Figure 23) is that it doesn't have a permanent volume of water between two consecutive stormwaters. It provides gradual release of certain volume of water in order to increase settling of pollutants and protect downstream channels from frequent storm events. The retention of water usually lasts from 1 to 2 days and until the new inlet it assumes its dry form.

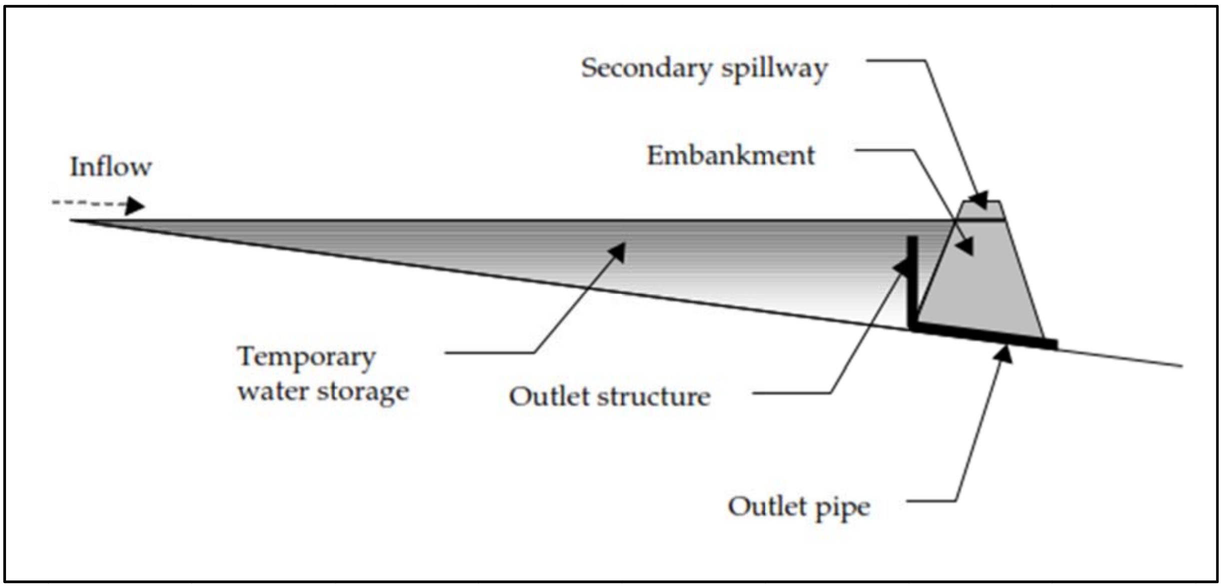


Figure 23: Example of Extended Detention Pond (EPA, 1997)

According to Urbonas (no year) removal rates for TSS range from 10 to 90%, depending on the constituent being sampled, the geometry of the installation, and the local climate. Although sedimentation is the main treatment process in EDP, there are evidences of other processes too. Some of them are:

- flocculation,
- agglomeration,
- ion exchange,
- adsorption,
- physical resuspension of particulates,
- solution.

EDP is considered to be adequate for areas with moderate permeability soils and for stabilised catchments smaller than 8 to 12 hectares. The retention time of 24 to 40 hours which we take as an example and in which 90% of TSS is eliminated is refering to the first flush of 13 mm (up to 20). If the precipitation amount is greater than 20 mm water must be retained for longer than already mentioned 40 hours to achieve the same degree of purification. But if the amount is smaller than 13 mm, proportionally with it, needed retention time will be shorter.

In order to have a gradual release of water, tubes that are used for this must be small in diameter and thus are vulnerable to easy clogging. Also an important characteristic for EDP is that it doesn't reduce the volume of the stormwater that enters it.

According to EPA (1997) advantages of this technology are:

- it can be appropriate in areas where stormwater runoff is insufficient or too unreliable, evaporation rates are too high or soils are too permeable to sustain the use of constructed wetlands,
- it could be used where the site area precludes the use of a constructed wetland,
- it has a potential for multiple use if it drains between two storm events (f.e. sport field or park),
- detention of stormwater reduces the frequency of erosive flows downstream,

According to the same source (EPA, 1997) disadvantages of EDP are:

- limited removal of fine sediment or dissolved pollutants (f.e. dissolved nutrients),
- potentially lower efficiency for events smaller than the design event,
- outlet structures are prone to clogging,
- potential for erosion and re-suspension of deposited sediment in the pond floor,
- possible safety hazard due to intermittent nature of flooding,
- possible maintenance problems and mosquito breeding from the frequently wetted floor.

Generally speaking, EDP (Malus, no year) can be used when:

1. it is expected especially large pollution of receiver (usually when the average daily traffic volume is over 30,000 vehicles/day and/or on burdened city roads),
2. it is necessary to reduce the impact of pollution from roads, and herbal treatment can not be applied,
3. the water management authorities require not to disturb the water regime due to changes in land use.

Land required for EDP is from 0.5 to 2.0% of the total catchment area. In the project and construction it is necessary to consider the infiltration capacity of soil below the lagoon along with high levels of groundwater. Usually they are narrow and elongated and they can be placed along the embankment slope, in wide dividing zones or in the free spaces of traffic loops.

5.1.4. Constructed Wetlands

Constructed Wetlands (CW) are treatment facilities in which we can find few different processes of stormwater pollution removal: physical, chemical and biological. According to EPA (1997) constructed wetland system (or wet basin in some literature) are usually consisting of an upstream pond with relatively deep water and macrophytes[50], and a shallower downstream wetland with developed macrophyte system (Figure 24).

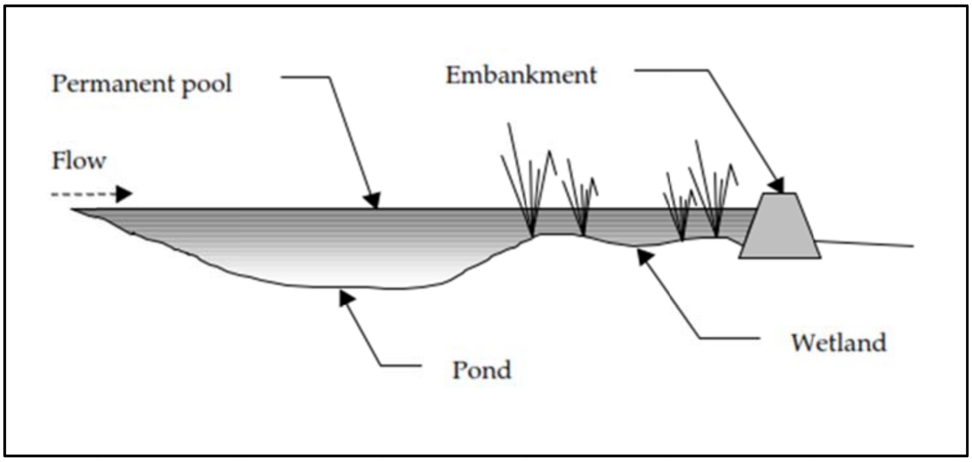


Figure 24: Constructed wetland with its consisting parts (EPA, 1997)

Each of these processes is distinguished by certain characteristics. Physical process is characterized with low flow velocity and is expressed as evaporation, precipitation, adsorption, and/or filtration (Malus, no year). Chemical process includes felling and chemical adsorption. Biological processes consist of a degradation, spending of plant nutrients and biological degradation and transformation. Hydrological factors act decisively to remove pollutants, since they influence the deposition, aeration, biological transformation and adsorption on the wetlands bottom sediment.

[50] aquatic plants that grows in or near water

Conditions that occur due to retention of stormwater are suitable for development of wetland plants and microbial populations which can extract soluble carbon and nutrients and potentially reduce BOD and fecal coliform[51] levels concentrations. Despite this Constructed Wetlands can't have the full range of ecological functions as natural wetlands as they are designed specifically for flood control and water quality purposes. Constructed Wetlands require relatively large drainage areas and dry weather base flow which is crucial for maintenance of such facility (Corson, 2006).

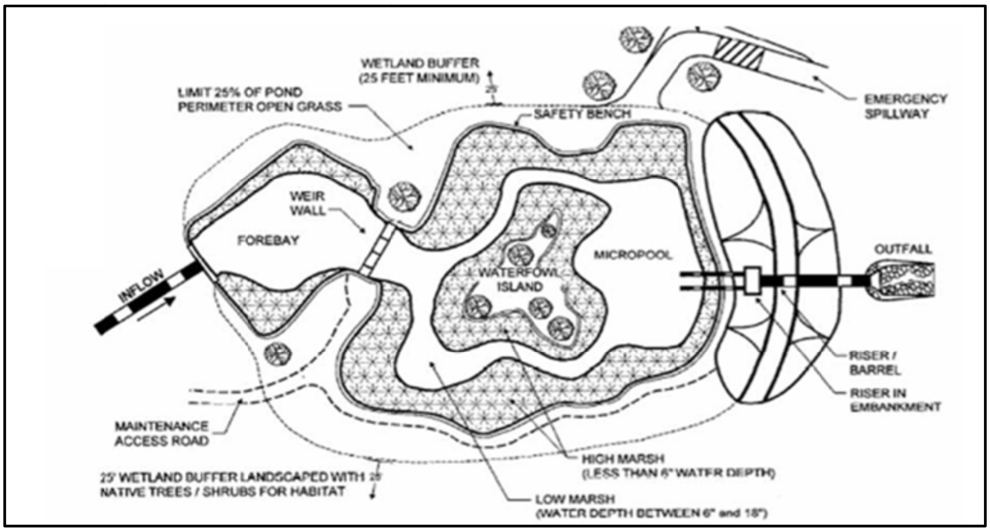


Figure 25: Schematic of Constructed Wetlands (Corson, 2006)

To clean the inflow stormwater from highway natural and artificial wetlands are used. Use of existing natural wetlands is better than artificial from an economic point of view but is also really hard to maintain because of various restrictions, legal and environmental.

Natural Wetlands are determined by type of soil (undrained soils, saturated or flooded with a thin layer of water), hydrological factors and type of vegetation that covers them.

[51] primarily Escherichia coli

Advanteges of Constructed Wetlands (modified according to EPA, 1997) are:

- principal water quality objective is the retention of fine sediment and nutrients,
- comparatively high retention efficiency for a range of runoff event sizes,
- potential for multi-objective designs to provide habitat, recreational and visual amenity,
- a flood storage component can be included to attenuate downstream flows,
- can be applied for catchment areas larger than 2 – 4 hectares,
- in combination with the wet lagoon or other protective structures provide high efficiency of cleaning and can match the larger basins,
- appropriate planning and design can reduce maintenance costs.

From the same source, disadvanteges are:

- pre-treatment is needed to remove coarse sediment,
- they need a steady flow of water,
- potential impact on public health and safety from a physical, chemical or biological perspective,
- large inflow could have an impact on groundwater, or groundwater could have an impact on the wetland,
- relatively large land requirements,
- they need to be regularly maintained cutting plants and removing debris,
- it is a longlasting process as it takes some time to establish plant and animal communities and achieve the desired performance,
- forming the strict geometric shapes is out of the question because we need to achieve a natural look.

5.1.5. Wet Pond

Wet Pond (known as retention basins or shortened WP) is a facility that treats stormwater for water quality by utilizing a permanent pool of water to remove conventional pollutants from stormwater through sedimentation, biological uptake, and plant filtration (National Research Council, USA, 2008).

It removes sediment, organic nutrients, and trace metals from stormwater and by slowing down stormwater using an in-line permanent pool or pond effecting settling of pollutants. Biological processes occurring in it reduce the amount of soluble nutrients present in the water (f.e. nitrate or phosphorus). In order to achieve high pollutant removal efficiencies for total suspended sediments, phosphorus, and nitrogen, volume of the permanent pool has to be at least three times the water quality volume[52]. Good shaping of the pond can help to improve the performance of it and by maximizing the distance between the inlet and outlet (figure 26). In this way we provide more space, and in the end more time, for mixing of the new stormwater with the already existing pond water from previous events and also more time for settling of pollutants.

Soil conditions are also really important for the proper functioning of the wet pond as the pond is a permanent facility (has a permanent water layer), and thus must be constructed in soils with low infiltration so that the water can not be allowed to exfiltrate from the permanent portion of the pond. But if we have a soil with a high infiltration rate, deposition of silt at the bottom of the pond will help slow infiltration. In the cases where we have extremely permeable soils present at the construction site, a geosynthetic or clay liner may be needed.

Wet Pond is used for situations where the catchment area is not only represented with impervious layer of the road, but also with wider surrounding area and when we have a constant source of water needed to maintain this kind

[52] the volume that needs to be treated

of facility. In other situations (where we have smaller catchment areas or non-permanent source of water) Extended Detention Ponds are recommended.

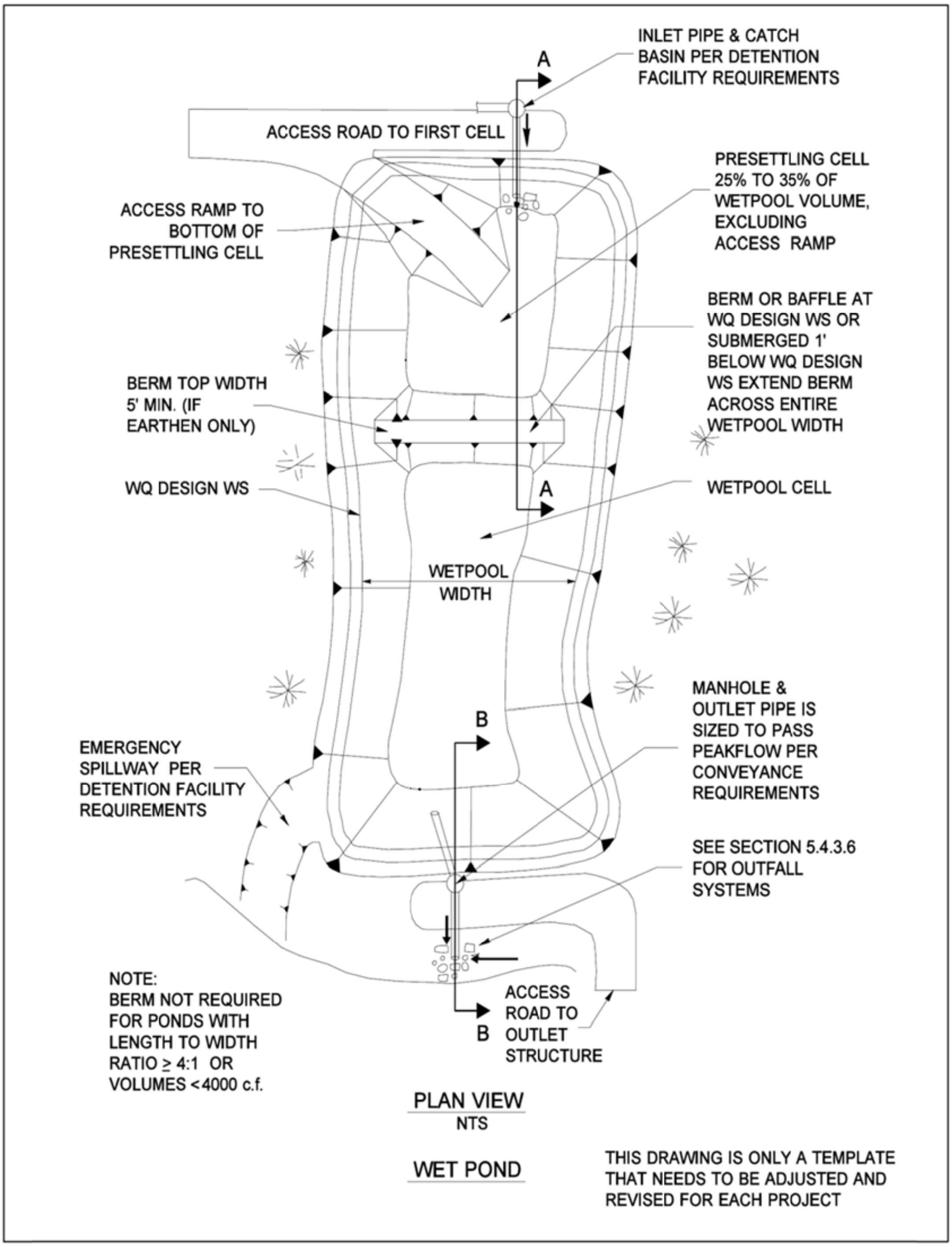


Figure 26: Plan view of a typical Wet Pond (WSDOP, 2011)

Wet Pond is suitable for usage for catcment areas with solid water sources and areas bigger than 4 hectares, but not more than 260 hectares (Malus, no year). If the pond is not well maintained, water in it can become staled and covered with algaes and floating waste. It can also have unpleasant odour and potentially become full of insects. For building a Wet Pond we have to secure 1 to 3% of its overall catchment area.

Wet Ponds can be designed in two basic sizes: basic and large. Basic Wet Ponds are approved as the basic stormwater treatment Best Management Practices (BMPs). Large Wet Ponds are designed for higher levels of pollutant removal and are an appropriate treatment BMP for phosphorus control. Usually, large Wet Ponds are 1,5 or more times bigger than basic Wet Ponds. It is recommended that all stormwater runoff treatment BMPs that use permanent wet ponds use facility liners (WSDOP, 2011).

Treatment begins with the settling of larger particles in the sediment forebay. As we already mentioned, a permanent pool of water has to be maintained so that, for smaller storms, the new flows push out a volume that has had a chance to interact with vegetation and be “treated”. This volume is equivalent to an inch (USA) or 2,5 centimeters (Europe) of rain over the impervious surfaces in the drainage area. Thus, what exits Wet Pond during smaller storm events is stormwater that entered the pond during previous storm event (National Research Council, USA, 2008).

Vegetation is considered to be a really important factor for pollutant removal. Wet ponds are designed with an aquatic benches all around the edges to promote contact with plants. According to National Research Council (USA, 2008.), vegetation has a few different impacts in this facilities:

- it reduces the flow velocities,
- it provides growth surfaces for microbes,
- it takes up pollutants,
- it provides filtering.

According to Corson (2006) general advantages of this technology are:

- it can achieve 80% TSS removal as a stand alone BMP,
- variable ability to accept pollutants from hotspots,
- low construction cost,
- low to moderate maintenance cost,
- moderate community acceptance,
- medium wildlife habitat benefit,
- provides water quantity benefit in the form of stormwater runoff rate control,
- long effective life,
- can act as sediment basin during construction phase,
- retrofit opportunities for existing wet ponds,
- large sediment storage volume below water.

According to same source, disadvantages of Wet Ponds are:

- it requires additional right-of-way beyond standard clear zone limits,
- removal rates vary widely depending on site conditions and storm events,
- minimum set-back from high water level required,
- heavy storms may resuspend sediments,
- potential for mosquito breeding areas,
- adequate source of water needed to maintain permanent water pool areas year round,
- water can become stagnant,
- evaporation can concentrate levels of salt and algae.

5.1.6. Infiltration Trenches

Infiltration trench (IT) is a trench, ditch or canal lined with filter fabric[53] (geotextile fabric) and filled with stone to make an permeable underground tank. Removal process that is characteristic for this system is infiltration, i.e. ability of soil to absorb water due to its porosity. Stormwater that enters a trench gets infiltrated into the surrounding soil but if volume of inflow is greater than infiltration it engages in a perforated tube that ends in the exhaust construction. According to Malus (no year) the depth of the trench is from 1 to 2.5 meters but can be changed according to local conditions. While the smaller trenches are designed to treat stormwater flows bigger ones can also be used for regulation of the flow. This is possible only in some cases where inflow is not to big because along with the growth of the inflow we have to increase porosity which can lead to weakening of the purification process. Infiltration Trench (figure 27) is usually not suitable for use in dense urban areas or in cases of reconstruction, if the soil has low permeability or a small proportion of voids. In general, they should be constructed after the stabilization of catchment area in order to reduce the flow of sediment. They cannot operate properly in soils with high clay content or in hardened soils with low water absorption (NTUA, no year).

Infiltration Trenches effectively remove solids and dissolved matter from stormwater. Along with purifying they also enrich the groundwater. In that manner they engage 60-90% of stormwater to the soil. Its are used for catchment areas up to 4 hectares. Locations where they are used the most are urbanized areas, parking lots, highways, and the area along the embankment.

[53] Artificial fabrics which are partially permeable and are used as a medium for filtration and collection of sediments

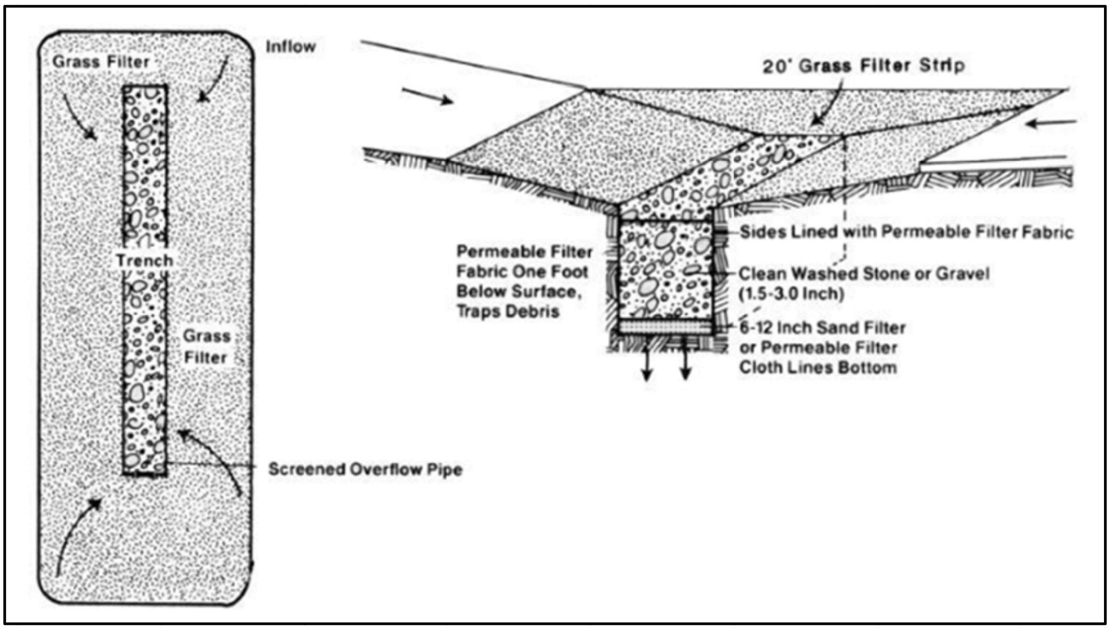


Figure 27: Infiltration Trench (Corson, 2006)

They provide pollutant reduction, stormwater attenuation for small sites, and groundwater recharge. The maintenance requirements for ensuring proper trench operation are high because also trench monitoring should be undertaken at least once per year or after every strong storm event. Maintenance includes the removal of debris and vegetation control. (NTUA, no year)

ITs are effective only on permeable soils such as sand and gravel and where the groundwater level and impervious layers are low below their bottom. They are used often in combination with grassed trenches and ditches and other protective structures that are effective in removal of sediment.

Considering that by its nature Infiltration Trench is extremely susceptible to sediment buildup and clogging it should be placed after another stormwater treatment or pretreatment facility because stormwater can contain high levels of sediments or hydrocarbons (f.e. oil and grease) which can cause previously mentioned clogging. As pretreatments, techniques such as vegetated filter strips or grassed swales can be considered. Precipitators can be built before Infiltration Trenches and used as a protection against coarse sediment.

During the construction of IT it is difficult to control the income of sediment which can eventually cause clogging of the filter layers or stone filling of the trench. Therefore, the best precautionary measures are the ones controling erosion of the surrounding soil.

Tipical lifetime of good maintened Infiltration Trench is betwen 10 and 15 years. According to Corson (2006) and Malus (no year) if the effective removal of coarse sediments before entering Infiltration Trench is not provided its expected lifetime gets reduced to only five years.

According to EPA (1997) and from Horton et al (1994) and modified according to Malus (no year), in practice there are 3 main types of infiltration trench systems:

- Shallow excavated trenches filled with rock that receive surface runoff. They are complete infiltration trenches where the infiltration is only possible from the rock filling of the trench and into the surrounding soil. This is the most common type of infiltration trenches;
- Partial infiltration trench where the stormwater flow infiltrates through the perforated drainage pipe system that distributes stormwater into the subsoil through a gravel trench. This solution is used in cases where there is a risk of reducing the permeability of the lower layers of soil or blockage at the contact of soil and filter fabrics. In some cases instead of the low-perforated drainage pipes high set perforated pipes can be used;
- First flush infiltration trenches ('French' drains) are trenches that have the specific role of removing pollutants from stormwater flows with highest pollutant concentrations, first flushes.

Greatest disadvantages of this treatment system are high construction cost, mandatory groundwater monitoring (due to risk of contamination in very coarse soils) and accumulation of metals and petroleum hydrocarbons to potentially toxic levels.

5.1.7. Infiltration Basins

Infiltration Basin (IB) is open space earthen building that captures the first volume (first flush) of stormwater inflow and purifies it by filtering it through the permeable soil. By percolating it, polluted stormwater is exposed to physical, chemical and biological processes that remove suspended and dissolved contaminants. As usual when it comes to filtration, sedimented pollutants stay on the upper soil layer while cleaned stormwater flows directly to groundwater. Infiltration Basins are usually used for the catchment area of between 0,8 and 8 hectares. For areas less than 0,8 hectares Infiltration Trenches (IT) which we already mentioned in previous section are suitable and for the catchment areas of more than 8 hectares, maintenance becomes too complex, so the use of Extended Detention Ponds (EDP) or Wet Ponds (WP) is more favorable. Infiltration Basins (figure 28) are generally dry except immediately following storms, but a low-flow channel may be necessary if a constant base flow is present (Corson, 2006).

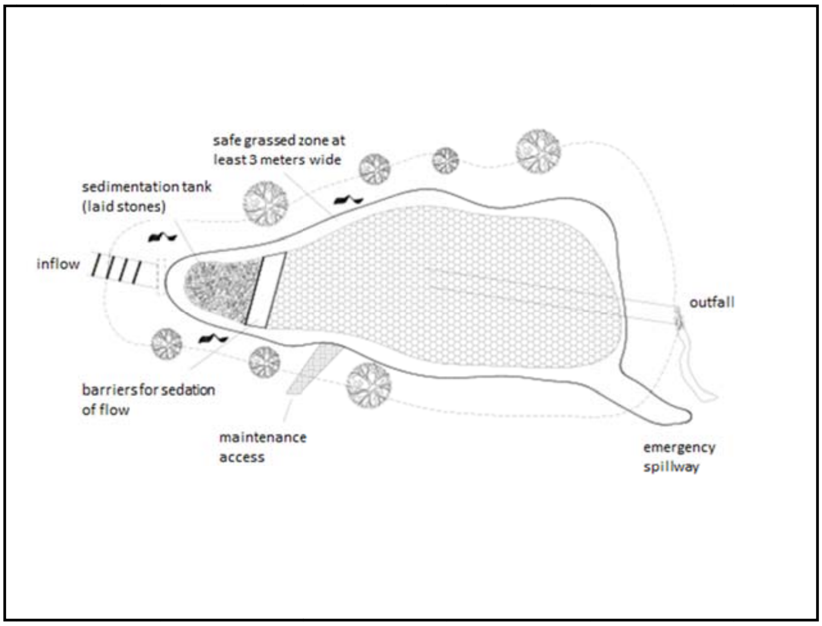


Figure 28: Complete Infiltration Basin (modified according to Malus, no year)

According to Urbonas (no year), properly operating Infiltration Basins can remove anywhere from zero to as high as to 98% of the pollutants from stormwater, depending on the constituent and site conditions. Also they can reduce the volume of stormwater runoff and virtually eliminate direct surface runoff for small storms under which we consider events with less than 1,3 to 2,5 centimeters of precipitation. Unlike Infiltration Trenches, Infiltration Basins do not include a stone reservoir storage.

Infiltration basins should not be used for industrial and commercial sites because of the potential to be susceptible to discharging of pollutants such as gasoline, oils, and solvents because they can cause soil and groundwater contamination (Urbonas, no year).

According to Malus (no year) it is extremely necessary to carefully choose the location of the Infiltration Basins. One of the most important parameters which have to be taken into consideration is soil permeability. If the soil is poorly permeable, percolating will be too slow and there is a possibility of flooding after new incoming events.

The other important issues are:

- the slope of the soil in the basin,
- the depth of waterproof layer,
- the groundwater level,
- closeness of drinking water wells,
- closeness of foundations of facilities.

When we want to check soil properties on some certain location we have to make many samples and from the depth of at least 1,5 meter from the planed bottom of future facility. Based on some earlier studies and according to Malus (no year), general criteria is that the filtration rate of soil on which we build Infiltration Basin shouldn't be below 7 mm/h. Also, soils which are consisted from 30 or more % of clay should be considered inadequate.

IB should not be built in basins with a greater decrease of 20%, and the container shouldn’t have a fall of more than 5%. The bottom of the tank should be at least 1,2 meter above the waterproof layer, and 0,6 to 1,2 meters above the highest seasonal groundwater level. IB distance from drinking water sources should be at least 30 m, because it has a potential to cause pollution. Because of possible leaching IB should be placed at least 3 m downstream and at least 30 m upstream of the building foundations.

Modified from Corson (2006) and EPA (1997) general advantages of this system are:

- provides groundwater recharge,
- can achieve 80% TSS removal rates as a stand alone BMP,
- medium construction cost,
- moderate community acceptance,
- appropriate for areas with moderate permeability soils.

Modified from the same sources biggest disadvantages of this system are:

- moderate to high maintenance cost,
- low wildlife habitat benefit unless vegetation,
- metal and petroleum hydrocarbons can accumulate in soils to potentially toxic levels,
- cannot be placed on steep slopes, fill or unstable areas,
- risk of groundwater contamination and low dissolved pollutant removal in coarse soils,
- mustn't be used in karstic regions.

5.1.8. Sand Filters

Sand Filters (SF) are beds of sand (sometimes it can also be other medium[54]) through which stormwater flow passes (as a specified design flow) and the concentration of pollutants gets reduced to an acceptable level. After that outflow can be discharged into the environment. SF can be placed above or below ground and it is typically designed to treat only the first flush of stormwater runoff, avoiding larger flows (Arika et al., 2006). It can be placed within existing infrastructure or under parking lots, and so it doesn't take up land that may be used for other purposes and which is commonly main economic factor. On the figures 29 and 30 we can see an examples of original Austin[55] Sand Filter.

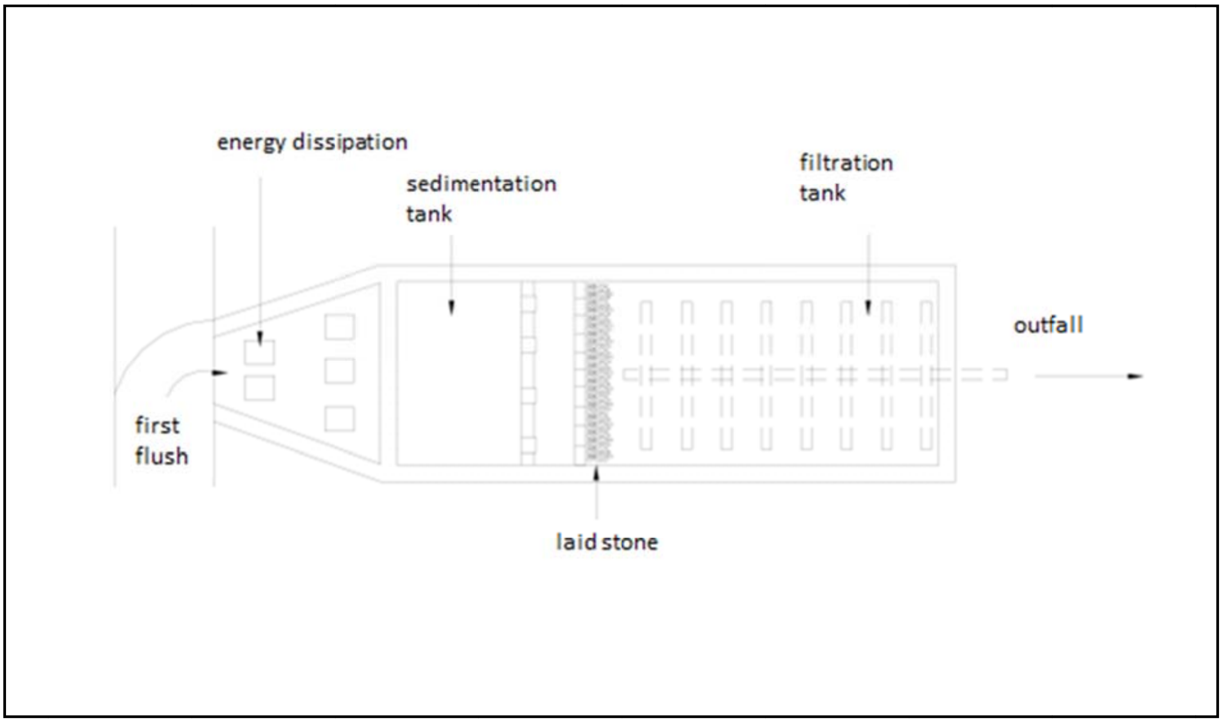


Figure 29: Layout example of Sand Filter (Malus, no year)

[54] peat, limestone and topsoil are other commonly used filter mediums
[55] first slow sand filter used in 1980s in Austin, Texas – name comes from name of the town

Sand Filter can be open or covered building. To function properly, oils, grease and coarse particles should be removed by some kind of pretreatment facility. The system of drainage pipes that is placed under the filter layer collects filtered water and chanels it and discharges into the environment.

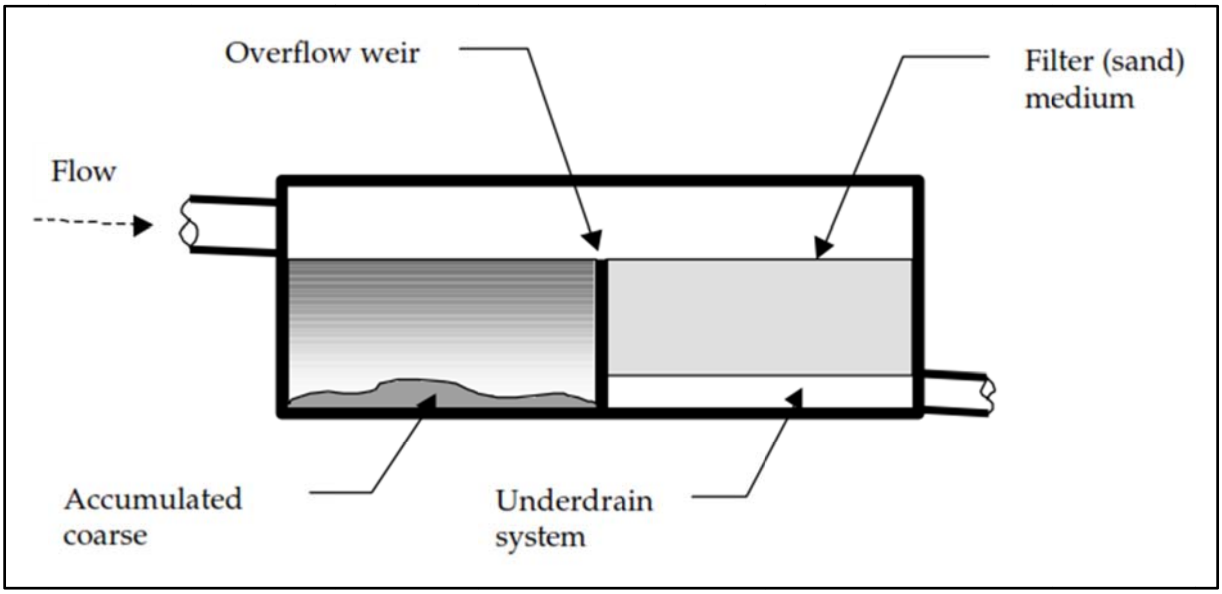


Figure 30: Cros section example of Sand Filter (EPA, 1997)

The Sand Filter is used and trusted as a treatment technology in many regions. It is used especially in regions where stream geomorphology is not problematic and where peak flow control and stormwater volume reduction are not the primary goals (NRC[56], 2008). The processes which occurs primarily are straining and sedimentation.

Main target of Sand Filter is to remove contaminants and suspension from the first flush of stormwater. Filtration which happens in this system targets primarily nutrients, organic compounds and coliform bacteria, i.e. suspended solids and ammonia nitrogen.

[56] National Research Council of the United States of America

During action of SF inside and on the surface of the filter biofilm[57] gets created, which furthers the process of filtration by allowing further development of microorganisms that can remove certain pollutants that otherwise would not be removed only by the filtration. According to Malus (no year), one of the main characteristics of SF is flexibility and adaptability so it can be used in catchments with thin soil covering, high evaporation values, low infiltration values and limited space and also in cases where the protection of groundwater needs to be seriously considered. These buildings are persistent in their work and they have small frequency of failures in performance if they are properly constructed, used and maintained.

Sand Filters are especially good choices for arid or semi-arid regions where survival and maintainance of vegetation based facilities is really difficult, sometimes even impossible. They are also applicable for regions with high temperatures which can also be restricting factor for development of some types of plants and in karstic regions (f.e., such as Croatia). If they are used in colder climates, special attention should be dedicated because biological effect of the facility is weaker there due to the lower temperatures.

If we want to have quality and long lasting facility Sand Filters must be provided with an upstream treatment or pretreatment system to remove coarse sediments and to distribute the inflow evenly across the sand filter because if we have concentrated flow with high velocities filter layer can be washed away or at least dispersed and mixed with other particles. As the biggest threat to the efficient work of the filters is abundant supply of suspensions and as a precautionary measure it is necessary to protect corresponding catchment area against erosion. The pretreatment system which is commonly used is sedimentation system which intends to trap coarser particles like sand and gravel, while the filter can remove finer particles such as silt and clay.

[57] an aggregate of microorganisms – mostly extracellular DNA, proteins, and polysaccharides

According to EPA (1997), there are two main types of sand filters:

- large sand filters which are suitable for catchment areas of up to 25 to 50 hectares, which includes a pretreatment basins; these type can have topsoil and grass cover and can treat flow from floodways or piped systems,
- small sand filters placed in underground chambers which are generally applicable for highly impervious catchment areas of up to 2 hectares; they are usually installed within the piped drainage system.

Advantages of this system are, according to EPA (1997):

- it is appropriate in areas where stormwater is insufficient or too unreliable (there is no permanent water layer present), evaporation values are too high or soils are too pervious;
- it is appropriate for retrofitting, sites with space limitations and underground installations;
- it is generally suitable for stabilized and largely impervious catchments all up to 25 hectares;
- it can be used in karstic regions where obligatory regulations and requirements are strict.

As modified from the same source, disadvantages of this system are:

- limited removal of dissolved pollutants;
- requires upstream pretreatments;
- easy clogging and sensitivity to the quality of maintenance;
- low flow rates through the filter;
- aesthetically unattractive in large forms and without vegetation cover.

5.2. Technical based treatment facilities

Technical based treatment facilities use a combination of physical, biological, and chemical processes to achieve the treatment objectives. In this kind of facilities the processes that occur mainly imitate natural ones but in an artificial environment, with mechanical components. A series of tanks, pumps, blowers, screens, grinders, and other mechanical components to treat stormwaters are used and inflow of stormwater in the system is controlled by different types of technical instrumentations.

Main advantage of these systems is that their location can be planed based on evaluation system which can contain economic or ecologic factors so they can be placed in less important areas with minimizing their impact on the surrounding. They usually take less space than the natural based ones and for the same pollutant removal efficiency.

The main problem, in the other hand, with them is their price. Cost of construction and especially maintenance is really high comparing it to natural based systems. Technical experts and specific mechanical parts are needed in order to preserve their functionality. In general, constant monitoring is needed and they don’t fit in well into the environment, from aesthetical point of view, as the natural based treatment facilities.

5.2.1. Technical filtration

In the wastewater treatment processes the first step in most cases is physical removal of bigger suspended particles from wastewater before continuing with more delicate stages. This is also applicable for stormwaters from highways. There are two main types of filtering processes: rough and fine filtering. Because of the variety of available technical filtration systems only an insight based on some generalized examples of these decentralized methods will be given.

Rough filtering (rough screening in some sources) is usually the first step in stormwater treatment. It is purely mechanical system, which cleanses big particles from flow so the second stage systems (fine filters (Sand Filters), Wetlands,…) wouldn't be clogged which in the end leads to malfunction of the whole treatment facility. There are two main types of rough filters for stormwaters from highways:

- Litter Baskets and Pits,
- Litter Rakes and Screens.

Litter Baskets and Pits (figure 31) are a wire or plastic 'baskets' installed in a stormwater pit to collect litter from a paved surface (litter basket) or within a piped stormwater system (litter pit) (EPA, 1997).

Their main characteristics are that they reduce downstream maintenance requirements, they are installed underground so they don't harm aesthetic experience on environment, they are used for smaller catchment areas and they need to be regularly cleaned and maintained. They are easily used as there are no developed and obligatory guidelines.

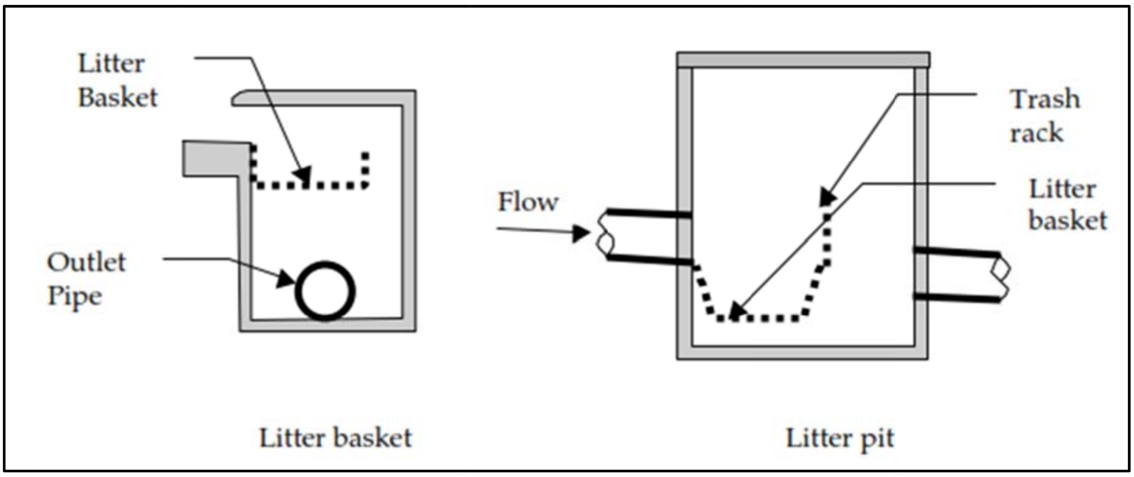


Figure 31: Examples of Litter Basket and Pit (EPA, 1997)

According to the EPA (1997) litter rakes (or in some sources trash rakes) are a series of metal bars located across a channel or pipe to trap litter and debris. Example of one we can see in figure 32.

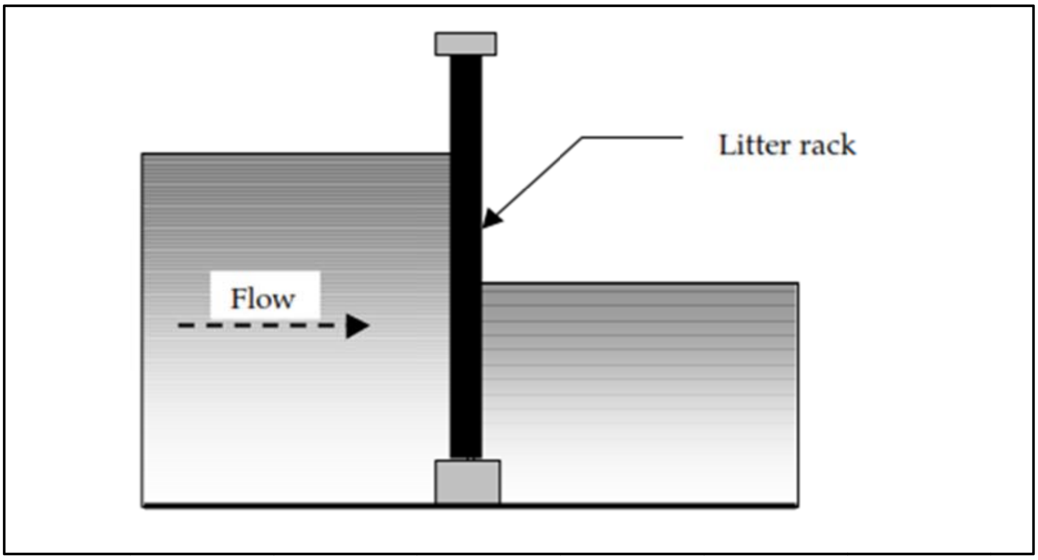


Figure 32: Example of litter racks (EPA, 1997)

They are used for catchment areas between 8 and 20 hectares large and are used as stand-alone treatment measures. General features of these systems are that they are appropriate for retrofitting into existing areas, they are difficult to clean and maintain, they have a tendency to be blocked by debris, previously caught material can be mobilized if clogging and overtopping occurs and they could potentially have an unpleasant odor. One more interesting characteristic is arrangement of racks depending on needs of system. Generally racks can have 3 different layouts: perpendicular, angled, staggered.

Second filtering type is fine filtering. This ‘second stage filtering’ includes filter elements with a multi-layer structure (Pfeffermann, 2011). Usually they are represented as relatively simple system installations. Sand Filters, which I already mentioned in context of natural based treatments, are most commonly used filters also in technical facilities and are considered single technical treatments. As filter layers also filter cartridges, geo-textiles, splitt filters, pol fabric filters or complex combinations[58] are being used. According to Pfeffermann (2011) this systems only hold back pollutants, if a filter cake forms on the surface of the filters. These filters can easily become clogged by dirt and small particles in general and that can cause flooding and additional expenses on maintenance. In the figure 33, we can see an example of multimedia (complex) water treatment filter consisting of gravel, sand and anthracite coal.

Figure 33: Multimedia water treatment filter [[14]; 18.05.2012.]

[58] high rate water treatment filters - a combination of filter medias is used, not just sand filters

5.2.1.1. Fine Filters

There are few different technologies used as a part of this group of systems and an insight into basic differences and performance information of sand, pile fabric and micro filters as well as the membrane filtration will be given.

Technical Sand Filters

Technical Sand Filters are non-vegetated systems consisting of washed filter sand with specially arranged granulometry and shaping, supplemented with calcium content, and if needed, covered with fine gravel (Pfeffermann, 2011). There are two types of these filters: slow and rapid (quick) ones. Rapid Sand Filters are mainly used in combined sewer system and their application on stormwaters from highways is not jet accepted. That means when we talk about treatment of highway stormwater, we always refer to Slow Sand Filters.

Sand Filters are systems used only for improvement of quality spectrum of stormwater and have almost non influence on flow rate control. On the contrary, if the flow is too turbulent, the efficiency is quite reduced. It can improve situation with turbidity and micro-organisms, especially bacteria and viruses. As the particles settle on the filter layer biofilm is made. It consists mainly of bacteria and has an ability to dissolve any organic particles that sediment down as well as very small inorganic particles. This layer is called ‘filth cover’ and it is of big importance for overall system performance. It requires an uninterrupted inflow in order to remain its properties. When the filter system is getting cleaned, along with it, biofilm is dispersed in the water. In order for biofilm to settle down again, filter tank can not receive any new inflows for period at about two weeks, which means that if we want to have continued treatment processes, we need to have two filter tanks present.

According to UNICEF (2009), pretreatment is necessary in order to maximize performances because maximum turbidity that can be present in stormwater inflow entering Sand Filter tank is 20 NTU[59]. Coagulation, flocculation and chlorination processes are not advised as pretreatments. Better choices are Oil/Grit Separators, Sedimentation Tanks and rough filters.

According to Pfeffermann (2011) water velocity when going through sand filters is between 0.05 to 0.2 m/h. Although biofilm is important part of system upper layer between 50 and 75 mm must be regularly removed.

Major limiting factors, according to EPA (1999), of this system are size and characteristics of the drainage area and pollutant loading. It needs routine maintenance to clogging of the filter and usually filter media needs to be replaced every 3 to 5 years.

Pile fabric filter and micro filters

These two technologies are described together because of the similarities in their working performances. Pile filter fabrics are also known as geotextiles or synthetic fabrics and are usually made of polypropylene, polyester, polyethylene, nylon, polyvinyl chloride, glass, and various mixtures of these materials (EPA, 2006). We can find them in in a wide variety to match the specific needs. These systems are used in order to remove fine particles (including heavy metals) from the stormwater. They can be found in various forms, as plastic or metal mesh (micro filters) woven, needle punched or heat bonded (geotextiles). Normally a diameter of pores of these filters is between 6 and 500 µm. During the process the particles are retained with the help of the tissue which allows the cleaning of the stormwater and from finer particles. Pile fabric filters are cleaned by a suction mechanism while micro filters are processed with high-pressure nozzles and the resulting sludge is sucked (Pfeffermann, 2011).

[59] Nephelometric Turbidity Unit - 1 milligram of finely divided silica per liter equals 1 NTU

Membrane filtration

Membrane filters are microporous films with specific pore size ratings. They retain solid particles and microorganisms larger than size of their pores. The principle of work is like in other filtration systems: it lets water flow through, while it catches suspended solids and other substances on its surface. Applications of high pressure or concentration gradient on both sides of the membrane and the introduction of an electric potential are some of the methods for enabling substances to pass through membranes.

According to Lenntech [[20]; 27.05.2012.], membrane filtration can be divided in two groups based on the types of particles they need to remove:

- micro and ultra filtration,
- nano filtration and Reverse Osmosis (RO).

As found in work of Schmollinger (2011) for removal of larger particles micro filtration (particle diameters of > 0.1 µm) and ultra filtration (0.1 – 0.01 µm) are applied but when salts need to be removed from stormwater, nano filtration and Reverse Osmosis are applied. The main difference between two groups is that nano filtration (0.01 – 0.001 µm) and RO membranes (< 0.001 µm) do not work on the principle of pores but on the diffusion through the membrane and they require higher pressure in order to efficiently perform.

Membrane filtration is applicable to treatment of stormwaters from highways but is not really widely accepted because its high costs, both in constructing and maintaining. It is mostly used in Water Supply treatment facilities.

5.2.2. Oil/Grit Separators

Oil/Grit Separators (also commonly called Water Quality Inlets, trapping catch basins or oil/water separators) are buildings which promote sedimentation of coarse materials and separation of free oil (as opposed to emulsified or dissolved oil). In these facilities sediment, oil, grease, and a large easily settleable particles from stormwater from traffic areas (highways) are removed before the wastewater is displaced or released into other treatment facility. In some cases they can be used in combination with sand filters.

A typical Oil/Grit Separator, as shown in the figure 34, consists of three different chambers:

- a sedimentation chamber,
- an oil separation chamber,
- a discharge chamber.

According to California Stormwater Quality Association report from 2003, these devices are appropriate for capturing hydrocarbon spills (mainly oil), but provide only superficial sediment removal. In general they are not very effective for treatment of stormwater runoff. Oil/Grit Separators typically capture only the first inflow of stormwater for treatment and are commonly used for pretreatment before releasing water to other treatment systems as they do not effectively deal with litter, nutrients, oxygen demanding materials or bacteria.

Oil/Grit Separators are primarily used to remove oil from stormwater runoff. But grit and sediments are partially removed too, and due to gravity settling within the first chamber (if needed, multiple chambers can even be placed). An O/G Separator with a detention time of 1 hour may expect to have 20 to 40 percent removal of sediments (CASQA, 2003 and Malus, no year).

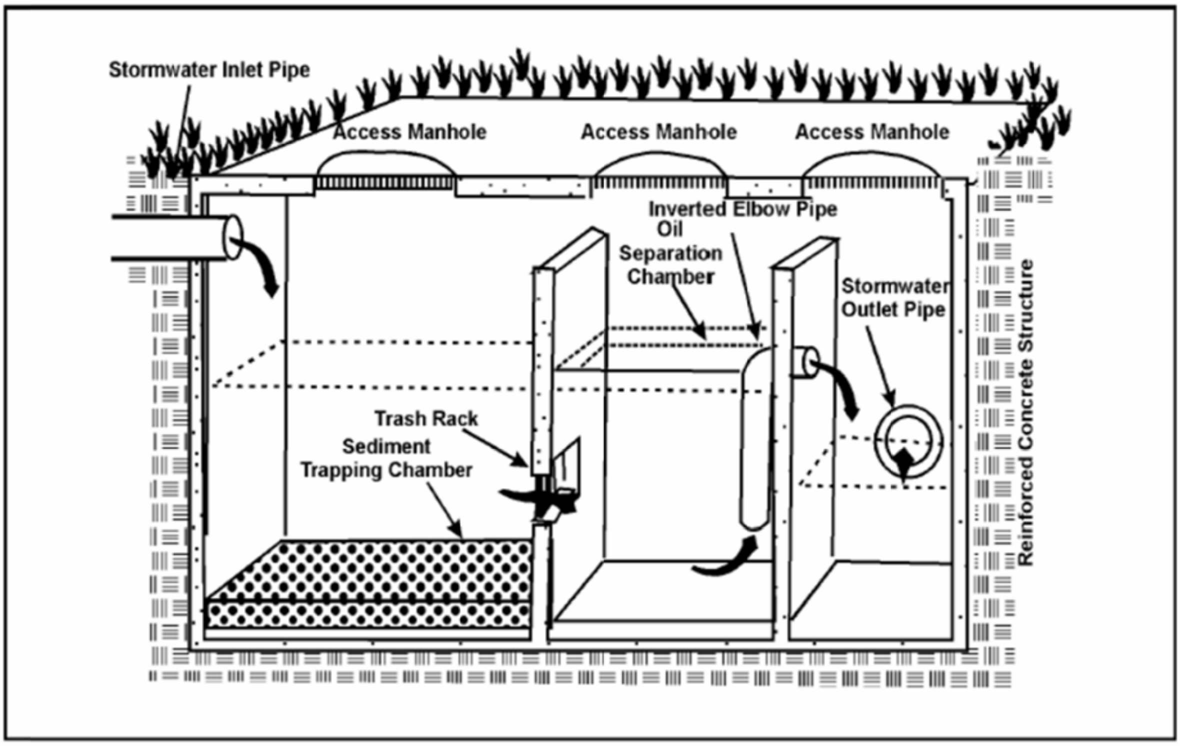


Figure 34: Oil/Grit Separator with sedimentation tank (CASQA, 2003)

The importance of this sort of treatment facilities lays in fact that floating layer of fat and oil makes oxygen intake, needed to sustain the process of purification, impossible.

As the stormwater inflow passes through the building very quickly, with a short stop, the results of removing coarse sediments, oil, grease and solid waste are moderate. They are used typically for the catchment area smaller than 2,5 hectares. In cases where high stormwater inflows are present, sediment that is deposited on the bottom of the sedimentation chamber can be dissolved and then can escape from the building. That is why regular cleaning and removal of sediment is required.

This problem can also be addressed with constructing a system with multiple (primarily) sedimentation chambers and in that case also dust particles can be removed to some extent.

According to Malus (no year) as the retention time in these facilities is no longer than 1 hour it can be concluded that the only larger and heavier particles of pollution are sedimented. Part of oil and oil floats on the surface of the separator, in the other hand, can be adsorbed on solid particles and deposited on the bottom.

Typical maintenance of O/G Separators includes trash removal if a screen, rakes or other debris capturing devices are used, and removal of sediment from the bottom as well as the floating oil from the separation chamber. This requires properly trained maintenance operators and that all parts of the separator that have to be regularly maintained are accessible at all times. A general timeline for checking the system status is not determined, but it is determined for individual technology by its vendor. Generally speaking, if we want to achieve maximum efficiency of our devices, the optimal maintenance includes a review approximately every 6 months. According to Pfeffermann (2011) the useful life of mechanical parts is 8 to 12 years and of the building parts from 25 to 40 years.

5.2.3. Sedimentation

The rest of decentralized technical based treatment facilities, which are in my field of interest, fall under the group of sedimentation facilities. In first part of this section I will describe some basics about the very process and after that I will go through most important information of each individual, most used, technology.

Sedimentation is a physical process in water where suspended solids settle down in regulated area under the influence of gravity or centrifugal force. In general, we can say that this is a process opposite to separation (which we already mentioned in previous section) where lighter particles (oil) are surfacing on top of the heavier ones (water). Here we have a heavy solids gathering on the bottom of water-filed limited area (when it is purely gravity forced system).

Clarified liquid leaving on the top of the sedimentation tank presents overflow while concentrated sediment sludge leaving on the bottom of the sedimentation tank presents underflow. Purposes of sedimentation are to remove coarse dispersed particles and coagulated[60] and flocculated[61] colloid[62] particles. Settling of coarse dispersed particles is characterized with no interaction between neighboring particles while flocculation causes the particles to increase in mass and settle at a faster rate. On process of flocculation I will say more in continuance of this chapter.

Suspended solids present in water tend to settle down by gravity as soon as the turbulence of the flow is retarded and approximate time of containing water for purpose of sedimentation is called detention period. In the other hand, when we use sedimentation by centrifugal force, turbulence of the flow is not a problematic issue.

Velocities of settling are determined with the shape, size and density of the solid particles. Although it can be calculated in theory, it is not completely correct

[60] outbreak of charge of colloidal particles
[61] growth of nearly neutral particles into larger clusters
[62] 10^{-4} to 10^{-6} cm big particles that can't be seen with the naked eye

to do so as the particles consisting in one pattern are not equal. They have different basic properties and one of the most important is how they react in contact with water.

According to Pfeffermann (2011), the resultant vector of the solid particle, settling velocity and the flow velocity characterizes the settling path of a solid particle in a laminar flow. Based on these results we can calculate the needed horizontal and vertical sedimentation path, which is function of settling time and settling velocity (figure 35).

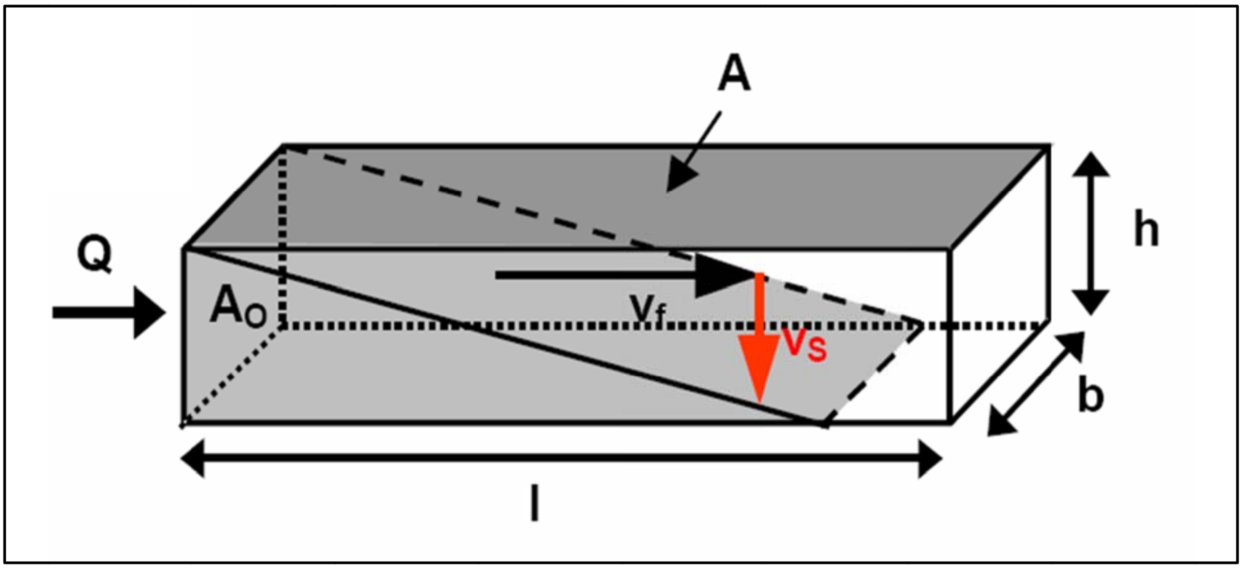


Figure 35: Settling process in retarded laminar flow (Pfeffermann, 2011)

5.2.3.1. Stormwater Sedimentation Tanks

Stormwater Sedimentation Tank (SST) is a structure placed within the stormwater system or upstream of other stormwater treatment facility and to trap coarse sediment, in a form of a formal 'tank' or a less formal pond (EPA, 1997). They are used only as a part of the separation system.

Based on their shape, there are two types of Sedimentation Tanks:

- rectangular (figure 36) and
- circular - or rarely square (figure 37).

In general, both types are usually equipped with mechanical sediment scraping devices for removal of particles settled on the bottom of the tank. Also any floating material is collected from the surface by a specific blades carried by mechanism, and is discharged along with the settled particles.

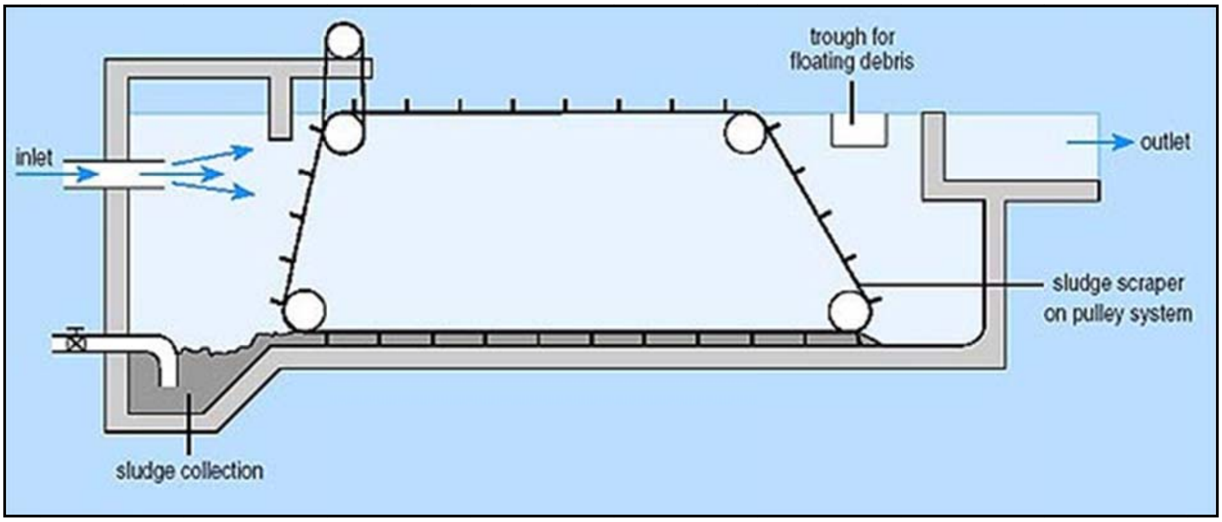


Figure 36: Typical rectangular horizontal flow sedimentation tank [[15]; 24.05.2012.]

Rectangular tanks have the simplest design, which allows water to flow horizontally. Sedimentation Tanks in form shown on figures 36 and 37 we find normally in combined sewage systems. Rectangular ones have many advantages such as cost-effectiveness, and easy and low-cost maintenance. The minimum length of flow from inlet to outlet depends on needed settling path for solids. Length is calculated based on smallest assumed particle of stormwater inflow. Ratio of length and width should be 3:1 (it can go up to 5:1). Length is the main disadvantage of this system because of space it takes up. As a decentralized system Sedimentation Tank normally occurs without any scrapers, but in an extremely simple version of just concrete tank which needs to be cleaned manually.

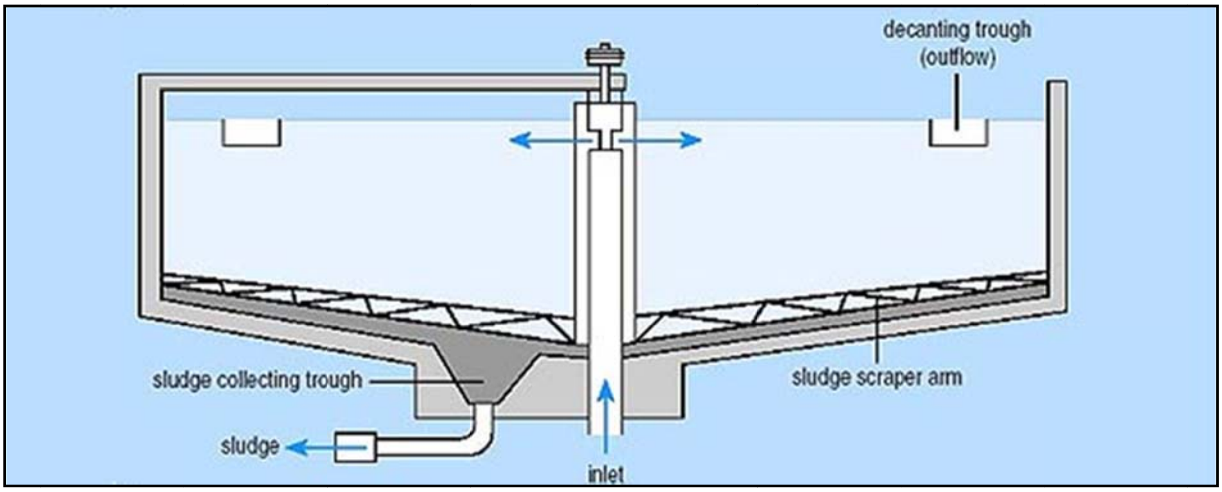


Figure 37: Typical circular (radial flow) sedimentation tank [[15]; 24.05.2012.]

In circular sedimentation tanks flow goes from the center outward. Such a flow pattern is great advantage as it allows the great chance for particles to settle without being mixed vertically. Horizontal mixing is better because water near the surface gets clean before water on the bottom and vertical mixing would bring dirty water upward which would prolong sedimentation process.

Circular sedimentation tanks diameters can range from 7 to 45 meters. Water depth on the sides of this system is smaller than in the center of the facility. Because of that inclination is present in the system which allows sedimented sludge to be easily removed.

According to Pfeffermann (2011) there are two types of stormwater sedimentation tanks:

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

Stormwater sedimentation tanks without permanent storage (figure 38) are constructed based on regulations and guidelines for stormwater storage tanks in the combined systems. According to Pfeffermann (2011), they are normally used in the situations where stormwater sewer is not constantly filled with wastewater. They can have normal or throttled overflow as well as the upstream structures with overflow and can perform as a temporarily buffer volume of the first flush. In case of heavy storm events where throttled overflow is present temporary connection to the wastewater sewer is needed.

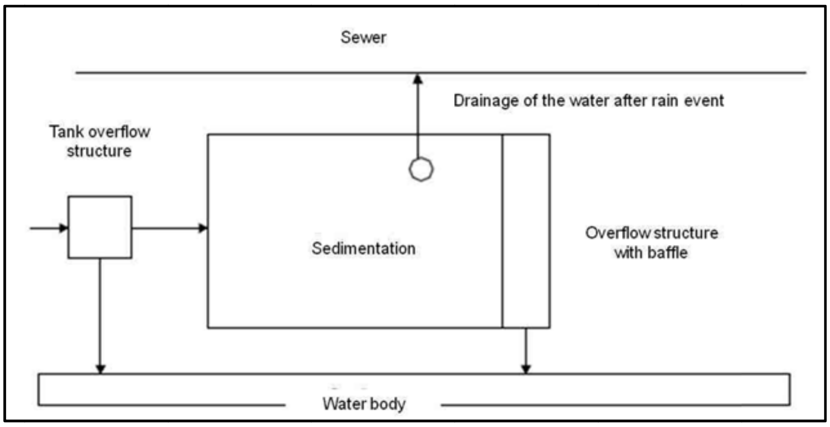


Figure 38: Sedimentation tank without permanent storage (Pfeffermann, 2011)

The main characteristic of stormwater sedimentation tanks with permanent storage is that they are always filled with stormwater. While in the sedimentation tanks without permanent storage smaller amounts of stormwater can't be efficiently cleaned, here that is not a problem. Because of the steady water volume in the tank there is a potential for anaerobic processes present, which could cause a re-dissolution of particle-bound pollutants (Pfeffermann, 2011). That is why ventilation of system is required in any form possible. This kind of tanks can be closed or open type where open type is natural based. Considering permanent storage volume for water, also an extra storage capacity for sedimented sludge needs to be secured, an extra volume of at least 2 meters depth.

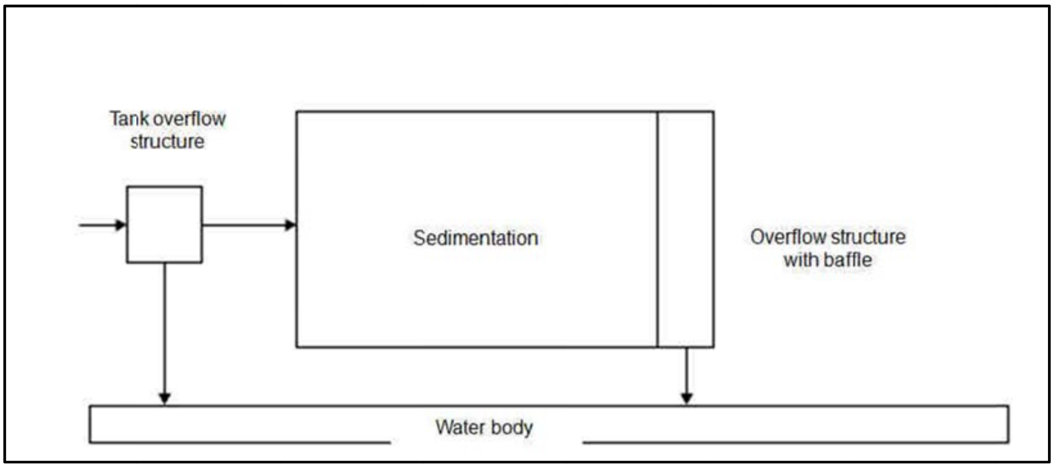


Figure 39: Sedimentation tank with permanent storage (Pfeffermann, 2011)

From the Pfeffermann (2011), with good maintenance and exploitation structural parts of stormwater sedimentation tanks can have a lifetime from 40 to 70 years. For mechanical parts lifetime is quite shorter, from 5 to 20 years.

5.2.3.2. Lamella Separators

Lamella Separators (figure 40) are one of modification systems of sedimentation tanks. They are used to enhance properties in general. Their design allows them to fulfill two main purposes:

- increasing of the settling area,
- obtaining a laminar flow.

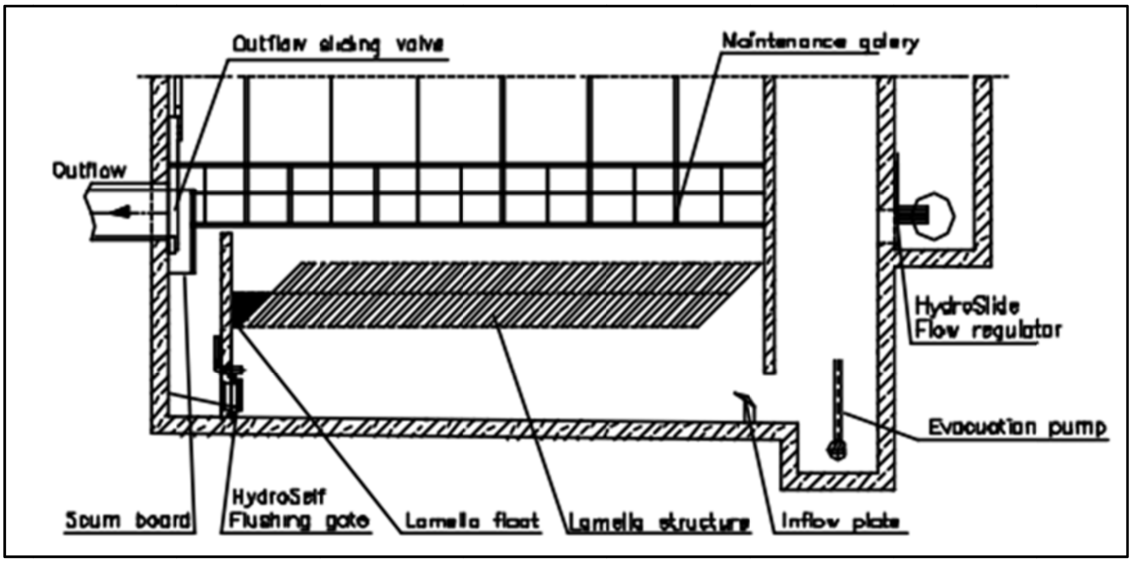


Figure 40: Cross view of typical Lamella Separator (Pfeffermann, 2011)

By dividing it and creating a number of smaller 'sedimentation tanks' we can increase the capacity of the original sedimentation tank. That is possible with the usage of lamellas. In general lamellas can occur in two characteristic types, as pipes (round, rectangular, hexagonal), as showed on figure 41, or parallel plates (lamellas). Lamellas are used to shorten the residence time of stormwater in the tank but with achieving the desired level of deposition and further stratified and stabile flow. The characteristic dimension of the pipes or distance between parallel plates is between 5 and 7 cm.

Figure 41: Lamella Separator with pipes [[17]; 26.05.2012.]

Normally, these systems consist of three main parts:

- inlet chamber in which stormwater flows directly before going to the settling stage,
- settling chamber with lamellas parallel arranged with an inclination angle,
- outlet chamber through which clarified water is sent for direct evacuation.

According to Pfeffermann (2011) lamella separators can consist also of a pumping and a flushing sump, an inflow shield and a scum board at the outlet.

When it comes to the very process of flow between lamellas the solid particles slide along the inclines of the lamellas onto the settling bottom, while the clean water rises to the surface. The water flows evenly through the lamellas from the bottom to the top and in order for our system to work, the settling rate of particles must be greater than the flow rate of water. This process can be achieved because of change of velocity of flow in relation to the proximity of the first obstacle. The velocity is smallest where the water contacts the lamellas and biggest at the middle point in between them. In that case solids contained in the stormwater move toward the surfaces of the lamellas where the velocity is smallest. That allows them to reverse their direction and to fall onto the bottom from where they can be later easily removed. This process is graphically described in the figure 42.

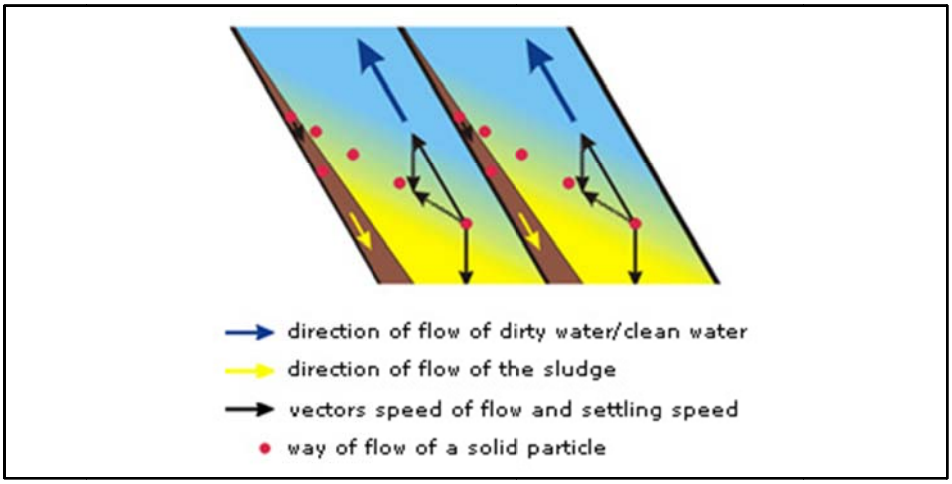


Figure 42: Generalized view of flow and sedimentation process in Lamella Separators [[16]; 26.05.2012.]

According to an internet source [[18]; 26.05.2012.], optimum angle of inclination of flow elements is between 45 and 60° which ensures continuous gravity flow and larger settling area for suspended particles that need to be removed. By careful determination of system potential of reduction in the required depth of water from about 30% is achievable.

As mentioned in work of Pfeffermann (2011) in some systems in an empty facility the lamellas are placed in vertical position. When the water in sedimentation tank raises the float that is attached to the first lamella rises also. This position of lamella we call the working position. When the storm event is over and there is no more inflow into the facility, drainage starts (pumping into the sewer system). Then lamellas fall down into a vertical position which allows the wet remained particles, which weren’t able to settle during the original process, to slide down and fall onto the gathered sludge on the bottom.

Lamella systems are usually made of fiberglass or stainless steel corrugated sheets. Stainless steel lamellas are quite easier to keep clean, they have really smooth surfaces and they don't collapse as much as fiberglass ones but greater stainless steel prices are the reason of bigger usage of fiberglass as a building material. Although more expensive, there are some predictions that the cost on maintenance and replacement pays them of in the long term.

Advantages of this system are its continuous operation, smaller needed volume, shorter filling and emptying time, modular design which allows future expansions if needed, high performance that is achieved for less time and lower capital costs.

Disadvantages in the other hand, are lack of buffer volume for potential fluctuations of the flow (can cause resuspension of solids), many required surfaces and sometimes insufficient storage capacity for the sedimented sludge.

In Lamella Separators no moving parts are present which means there is almost non necessity for frequently and thoroughly maintenance, except cleaning the lamellas every now and then. The cleaning of the lamellas can be performed by bubbling air through them or rarely with special vibrators. The only important requirements are that the lamellas must have a smooth surface so the solids can slide smoothly.

Basically, there are no restrictions on how big the lamella facilities can be. They can be made as small individual tanks for smaller catchment areas and all up to big facilities in combined sewer systems.

5.2.3.3. Vortex Separator

Vortex Separator is also one of the systems based on the principle of sedimentation. In order to separate solid particles from organics and, most importantly, liquids, it uses gravitational force supported with centrifugal and other rotational forces. It can remove solid particles from stormwater under relatively low head loss. Because of that it can achieve equivalent or even better cleaning results but with requiring smaller area. The different types of Vortex Separators offer solutions for different pollution problems and are characterized by their headloss and solids removal efficacy (Andoh, 2011). Originally, Vortex Separators were developed for combined sewer overflows for removal of coarse solids of inorganic origin but later they have been 'transferred' to stormwater problems by individual producers (CASQA, 2003).

Vortex Separators (figure 43) are effective at removing heavy particulates (such as gravelly materials) and floatables from stormwater. In the other hand, they are completely ineffective in removing particles with poor settling abilities.

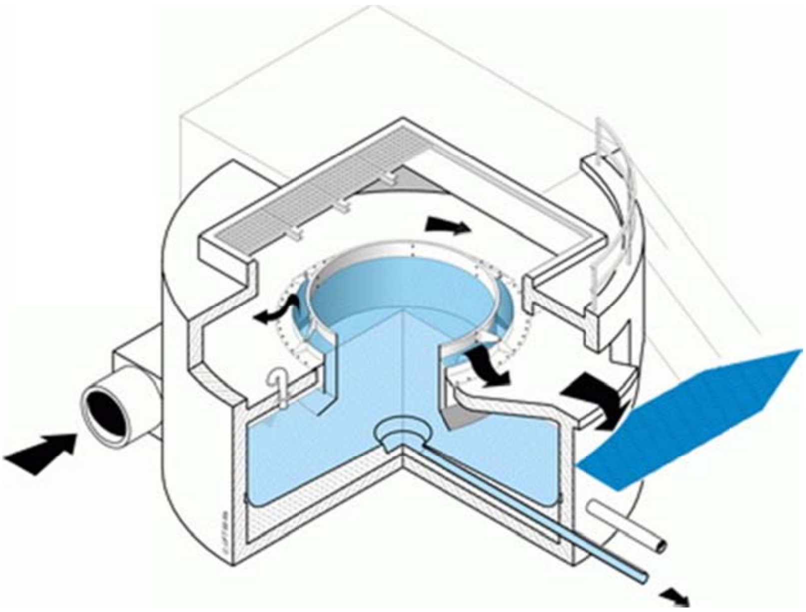


Figure 43: Typical Vortex Separator (Pfeffermann, 2011)

They work on the principle of combination of different forces as the stormwater enters tangentially into the system, imparting a circular motion into the system (CASQA, 2003). Along with cylindrical shape of the separator differences in flow velocities occur in the system. On the inner walls of the cylinder, highest velocities are present and they are decreased as the flow moves to the center of the system. Because of these effects, secondary vortices occur near the walls forming a zone of small horizontal velocities allowing a descent of pollutants (Schmollinger, 2012). Sedimented particles concentrate in a sludge channel and are released to a sewer by the sludge take-off. This makes cleaning of the vortex not needed (Pfefferman, 2011). Cleaned water is gathered in the middle of the device in between two baffles which when overload occurs are swamped completely and provide the required cross-section for the emergency outlet.

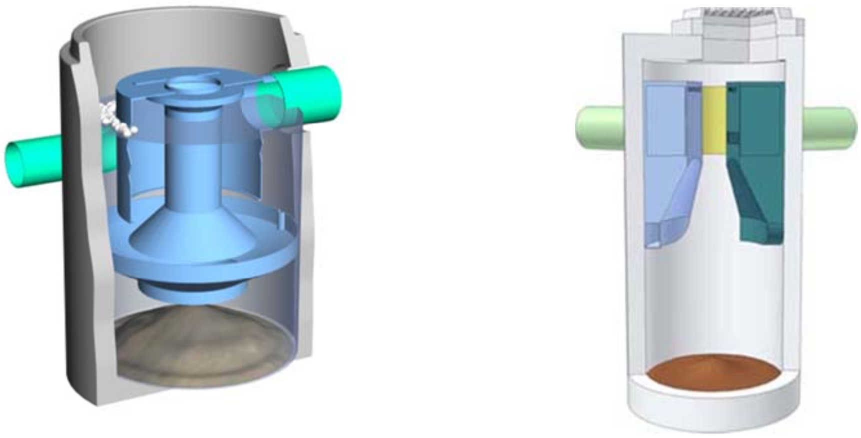
According to Andoh (2011), there are different types of vortex systems based on their head losses: with high, medium or low head loss. The main difference between systems is their width and sizes of particles they are capable of efficiently removing. From Pfeffermann (2011), main factors for the hydraulic design of a Vortex Separators are:

- the local height ratios,
- the expected maximum inflow Q_{max} and
- the outflow Q_{out}.

Advantages of these systems are: smaller space requirements; comparing to traditional basins they are more cost-effective pretreatment devices and they don’t need any special mosquito controls.

Disadvantages are: potential steady water between storms; they are not so effective with fine sediments (50 to 100 microns in diameter and less); standardized sizes cause, comparing to designed storm, oversizing in many cases which increases the cost; the non-steady flow of stormwater decreases the efficiency of vortex separators; do not remove dissolved pollutants.

There are two main representatives of vortex systems and are products of manufacturer named Hydro International. First is called ‘Downstream Defender’ (Figure 44) and it is an advanced version of Vortex Separators. It is applicable for control of sediment, floatable trash and petroleum products, for redevelopment projects, for streets, roadways and parking lots and as a pretreatment for filters, infiltration and storage facilities. Advantages of this system are good efficiency, small footprint, low capital cost, preventing of pollutant washout and low system head loss.



a) b)

Figure 44: a) ‘Downstream Defender’ and b) ‘First Defense’ from Hydro International [[19]; 26.05.2012.]

The other one is called ‘First Defense’ and is an enhanced vortex separator that provides stormwater treatment in a surface inlet device. It can be applied for small to medium size catchment areas, retrofits, as a source control for streets, parking lots and maintenance yards and as pretreatment for filters, infiltration and storage. Main advantages of this system are that it is a catch basin and separator in one device, it has built-in bypass for peak flows, it prevents pollutant washout, has compact and flexible design and has low head loss.

5.3. Systems Performances

When we talk about different treatment systems, every each of them can find their way into a modern stormwater treatment climate. Only question is in which manner they will be applied. Many of these systems operate as stand-alone systems while the others can work only in combined actions. This happens because of the differences of their performances and finally applicability on the certain situation that we refer to. Many detailed tests need to be conducted in order that a person in responsibility can make a best decision on the selection of the most suitable treatment system. Parameters that are most important regarding evaluation of different systems can be various and they depend on subjective decision of people in charge of this matter. Some of the evaluation factors and which I already described more detailed in chapter 2, are:

- TSS (Total Suspended Solids),
- Heavy Metals (HM – such as copper, zinc, lead or cadmium, but it really also depends on the subjective decisions),
- PAH[63] (Polycyclic Aromatic Hydrocarbons),
- BOD_5 (Biochemical Oxygen Demand of stormwater, or any other water and in standardized 5-day period),
- COD (Chemical Oxygen Demand),
- Nutrients (P^{tot} and N^{tot} – Total amount of Phosphorus and Nitrogen),
- Oil and Grease, etc.

All these parameters fall under the group of efficiency factors that one system can have based on researches and/or laboratory tests.

[63] atmospheric pollutants that can occur in oil, coal, and tar deposits, or can be produced as byproducts of fuel burning

There are also economic and land (soil) limitations that can be inducted into the evaluation system, such as:

- Construction Costs (CC),
- Operation Costs (OC) and maintenance requirements,
- soil permeability,
- water protection zones, etc.

The main problem with evaluation system is that it can't really be generalized and correctly implied to every situation because performances of treatment methods largely depend on external influences that occur in the catchment area in certain time. Their efficiency limits can't be strictly defined as their effectiveness depends on a number of factors that are extremely difficult to control, where the climate and the human factor are crucial. F.e., vegetation based systems are sensitive to the maintenance of vegetation cover and erosion processes, which doesn't affect procedures such as filtration and infiltration which are more sensitive on settleable material clogging the pores. So to know the quality of stormwater that comes into the system is as much important as meeting the quality requirements of water discharged from the system if we want to make satisfying decision. In principle, buildings which are same in structural and technological meaning can give different results of the effectiveness on different locations. Sometimes poor performance can be caused just by poor design and construction of certain parts of facilities.

In this section values of main performance parameters that I consider crucial[64] will be given. This will make basin for creation of evaluation and recommendation system as a part of chapter 6.

[64] subjective thinking is also a factor that needs to be considered as the experience or lack of it can fairly influence the decision of responsible engineer

Values of efficiency that are going to be presented in future text and tables are retrieved from different sources and are product of many researches provided over longer period and on various locations and samples. It has to be known that the values correspond with different conditions in the field and represent only the general averages of the researches. Emphasis is placed on performance, not on the methods and conditions for conducting research that are standardized for each region by certain laws (which I have dealt with in chapter 3) and which are different depending on the region in which they are implemented.

As the term Best Management Practices, from the point of sustained development, is normally used for natural based treatment facilities for stormwaters from highways, researches on their performances are more common to be found as subject of the specific research. On the other hand, attests for the technical treatment facilities are generally provided by the manufacturer of a technology and it is difficult to find independent and objective research values for these systems.

In table 12 we can see efficiency values modified according to many different sources[65]. It shows average boundaries of efficiency detained from different research results.

[65] Malus (no year); Corson (2006); EPA (1997); International Stormwater Best Management Practices (BMP) Database (2011); Young et al. (1996)

Table 12: Efficiencies for natural based treatments modified according to various resources

Treatment facility	Efficiency (%)						
	TSS	BOD_5	N^{tot}	P^{tot}	Metals	Bacteria	Oil/Grease
VBS[3]	27-70	N/A	20-40	20-40	2-80	N/A	N/A
GS[4]	75-100	10-50	50-75	50-75	N/A	75-100	75-100
EDP[2/**]**	80-100	40-60	40-60	60-80	60-80	N/A	N/A
CW[2/]**	80-100	40-60	40-60	60-80	60-80	N/A	N/A
WP[5]	80	N/A	27	59	51	93	N/A
IT[1/*]	75-99	N/A	45-70	50-75	75-99	75-98	N/A
IB[1/*]	75-99	N/A	45-70	50-70	50-90	75-98	N/A
SF[4/*]**	75-100	50-75	50-75	50-75	N/A	50-75	50-75

N/A – Not Available for analysis

Treatment facility types:

VBS - Vegetated Buffer Strips (Filter Strips)

GS – Grassed Swale

EDP – Extended Detention Ponds

CW – Constructed Wetlands

WP – Wet Ponds

IT – Infiltration Trenches

IB – Infiltration Basins

SF – Sand Filters (surface and/or underground)

Sources:

[1] Young et al. (1996)

[2] Malus (no year)

[3] Corson (2006)

[4] EPA (1997)

[5] International Stormwater Best Management Practices (BMP) Database (2011)

Conditions:

* Based on capture of 12.7 (13) mm of runoff volume

** Volume of the system is equal to 3/4 of the first flush volume of stormwater

*** Pretreatment for sedimentation and removal of litter is required

**** First flush volume of 25 mm maintained for 24 hours in the presence of the shallow water swamp plants

As we can see from the table, TSS removal is quite well represented with all the technologies, while it is not recommended to use them for oil and grease removal. Also oxygen demand is still quite high after usage of these facilities. According to these modified data obtained from different sources, overall best practice is Grassed Swale. It has to be emphasized again that efficiency of some treatment is function of many different factors from which some are sometimes hard or impossible to control. Comparison of different technologies is ungrateful because, in order to be representative, conditions and impacts need to be controlled.

Further on, capital construction costs and operational/maintenance costs are also important parameters for evaluation on system applicability. These values can be given in many different forms. For example, according to EPAs guide from 2006, values are presented as in table 13 or 14.

Table 13: Typical costs of BMPs presented in the form of dollars per cubic foot of treated stormwater (modified from EPA, 2006)

Treatment type	VBS	GS	EDP	CW	WP	IT	IB	SF
Typical cost ($/cf)*	0.00-1.30	0.50	0.50-1.00	0.60-1.25	0.50-1.00	4.00	1.30	3.00-6.00

$/cf - dollars per cubic foot of treated stormwater volume

* Based on dollar value in 1997

Table 14: Base costs of typical BMPs with excluded land costs (modified from EPA, 2006)

Treatment type	VBS***	GS***	EDP*	CW*	WP*	IT**	IB**	SF**
Typical cost ($/BMP)*	$0-$9,000	$3,500	$100,000	$125,000	$100,000	$45,000	$15,000	$35,000-$70,000

* 50-Acre Residential Site (Impervious Cover = 35%)

** 5-Acre Commercial Site (Impervious Cover = 65%)

*** 5-Acre Residential Site (Impervious Cover = 35%)

Operational/maintenance costs are usually determined and presented as the percentage of capital construction costs. According to the same source operational /maintenance costs are presented in table 15.

Table 15: Annual maintenance costs for BMPs (modified according to EPA, 2006)

Treatment type	VBS	GS	EDP	CW	WP	IT	IB	SF
Annual Maintenance Cost (% of Construction Cost)	$320/acre	5%-7%	<1%	2%	<1%	5%-20%	1%-3%	11%-13%

According to tables 13, 14 and 15 we can see that the most cost-effective treatment is Grassed Swale. For example, for 5-acre site with 35% of impervious cover, price would be $3,500 and the annual maintenance would be between 175 and 245 dollars. So when we also know, and from the table 1 that it is also best overall treatment it is logical to say that this is overall Best Management Practice for stormwater from highways. But that is not correct as the cost analysis has to be made for certain location and project where efficiency parameters origin from. Also the properties of stormwater have to be considered. The process of determining right treatment for a specific problem is long and it needs to be done thoroughly in order to preserve idea of sustained development. Of course, certain recommendations can be given and used as the basis for deciding but in the end full perspective needs to be viewed.

The last parameter in our field of interest is Land Requirements. This parameter is defined as the function of type of soil (hydrological soils group), area requirements, applicability of certain treatment system to specific types of soil, percentage of impervious layer in catchment area, etc. This general information has been given already in this chapter for each stormwater treatment system. In the next table (table 16), we can see an example of soil requirements and boundaries for some technologies.

Table 16: Types of soils with their infiltration rates and limitations of usage of BMPs (modified from EPA, 1997)

Stormwater treatment technology	**Soil type (infiltration rate)**									
	Sand (210 mm/h)	Loamy sand (60 mm/h)	Sandy loam (25 mm/h)	Loam (13 mm/h)	Silty loam (7 mm/h)	Silty loam (7 mm/h)	Clay loam (2.5 mm/h)	Sandy clay (1.3 mm/h)	Silty clay (1.0 mm/h)	Clay (0.5 mm/h)
VBS										
GS										
EDP										
CW										
WP										
IT										
IB										
SF										

Stormwater treatment technology can't be used on this type of soil

Usage of stormwater treatment technology on this type of soil is limited

Usage of stormwater treatment technology on this type of soil is not limited

When it comes to rating the applicability of treatment technologies compared to the infiltration characteristics of soil, we can see from table 5 that Extended Detention Ponds, Wet Ponds and Sand Filters have relatively small, almost no restrictions and can be used in nearly all soils.

As we can see, all the collected data from the previous tables is referring to natural based treatment facilities for stormwater from highways. That is mainly because technical systems don't have standardized values, but their characteristics and performance vary from manufacturer to manufacturer. Also the reason is the difference in the assortment of technologies, and by the various companies involved in it. This leads to a situation where the same technology has different performance due to certain modifications in the design and technological sense.

Also, when talking about natural systems, they are carefully defined and legally binding methods of design calculation exist by which we can adjusts them according to the conditions present on the ground, and after carefully conducted required analysis. That is the main difference between technological and natural systems as technological systems are pre-manufactured and cataloged according to certain characteristics. When they are used they are exclusively selected in accordance with the needs and then the optimal solution is made which doesn't always fully meet the requirements.

In general, technical solutions should be applied only in cases where natural solutions can't be applied for some reason.

6. EVALUATION SYSTEM AND PROPOSAL OF DEVELOPMENT PLAN FOR CROATIA

In the first part of this chapter an evaluation system for stormwater treatment technologies based on a literature study will be presented. Evaluation of 'Best Management Practices' will be suggested in order to ease the selection process. Generally speaking, at present time the emphasis is placed on sustainable development and usage of natural based treatment facilities in order to treat stormwater from highways as long as the conditions on the field allow it. Presented evaluation system is based on performances of these facilities but can easily be used for assessment of technologically based ones.

After that, in the second part of this chapter, recommendations for future projects in Croatia for expansion of highway road system will be introduced. Recommendations will be based on comparison of treatment limitations and ‘in situ’ situation, i.e. on information gathered from authorities and literature study of parameters such as already determined pollutant removal efficiencies of treatment methods, precipitation analysis for certain construction sites, geological limitations and of course, financial burden (cost-effectiveness).

6.1. Evaluation system of stormwater treatment facilities

This evaluation system is based on 5 grades system for every parameter in the field of interest. That means that every parameter can assume one of the grades based on its properties where 5 represents the best grade, 1 represents the worst one and grades in between are also functionally distributed. Every grade corresponds to certain limits which will be more explained through future text. If the data for some technology is not available then that parameter is marked with 0 which is not the grade of the system but only numeric status display. As there are 10 main parameters overall grade/value can go from 0 to 50. Objectively, if all the researches are conducted and all the needed data is obtained, the grade can't be less than 10 as the lowest grade for each parameter is 1 but theoretically it can be 0 if there is not any data for certain technology available.

Although all the parameters are separate and individual, first 7 parameters can be reviewed as one group. This first 'group' of parameters are the pollutant removal efficiency parameters and the ones that are going to be evaluated are:

- TSS (Total Suspended Solids),
- Heavy Metals (just Metals in future text (M) - copper, zinc, lead or cadmium are revered as the relevant ones),
- BOD_5 (Biochemical Oxygen Demand in 5-day period),
- P^{tot} - total amount of Phosphorus,
- N^{tot} - total amount of Nitrogen),
- Oil and Grease,
- Bacteria (Pathogens).

Removal efficiency parameters

Removal efficiency is usually presented as the percentage (%) of removal of pollutants that enter the treatment facility. It can be calculated as

$$Efficiency = \left(\frac{pollutant_{inflow} - pollutant_{outflow}}{pollutant_{inflow}}\right) * 100$$

where pollutant $_{inflow}$ represents the amount of pollutant entering system in stormwater and pollutant $_{outflow}$ represents the amount of pollutant exiting system in treated water which is displaced later on.

According to that we can say that treatment efficiency can go from 0% to 100% and it can be proved by simple manipulation of previous equation. If it is assumed, and just for this hypothetical situation, that amount of pollutant entering system as the part of stormwater inflow is 100 mg/l and that in one case amount of pollutant exiting system is also 100 mg/l while in other it is 0 mg/l, next equations are presented:

$$Efficiency = \left(\frac{100\frac{mg}{l} - 100\frac{mg}{l}}{100\frac{mg}{l}}\right) * 100 = \left(\frac{0}{100}\right) * 100 = 0\%$$

$$Efficiency = \left(\frac{100\frac{mg}{l} - 0\frac{mg}{l}}{100\frac{mg}{l}}\right) * 100 = \left(\frac{100}{100}\right) * 100 = 100\%$$

With these simple equations it is confirmed that efficiency can have a quality range from 0% when there is no removal present in the system and up to 100% when pollutants are entirely removed.

Based on the range of values of efficiency grades are going to be attributed as following in table 17:

Table 17: Evaluation system for stormwater treatment facilities

Grade	Grade explanation	Efficiency range
5	High	100% - 75%
4	High to medium	75% - 50%
3	Medium	50% - 30%
2	Low to medium	30% - 15%
1	Low (insufficient)	15% - 0%
0*	Data not available	Data not available

* Not part of grading system

This evaluation and grading system can be applied to removal of all pollutants that are mentioned in previous text: TSS, M, Bacteria, N^{tot}, P^{tot}, BOD_5, and Oil/Grease. Example of this is presented in tables 18 and 19.

Table 18: Efficiencies for technologies modified according to various resources

Treatment facility	Efficiency (%)*						
	TSS	BOD_5	N^{tot}	P^{tot}	Metals	Bacteria	Oil/Grease
VBS	27-70	N/A	20-40	20-40	2-80	N/A	N/A
GS	75-100	10-50	50-75	50-75	N/A	75-100	75-100
EDP	80-100	40-60	40-60	60-80	60-80	N/A	N/A
CW	80-100	40-60	40-60	60-80	60-80	N/A	N/A
WP	80	N/A	27	59	51	93	N/A
IT	75-99	N/A	45-70	50-75	75-99	75-98	N/A
IB	75-99	N/A	45-70	50-70	50-90	75-98	N/A
SF	75-100	50-75	50-75	50-75	N/A	50-75	50-75

* Details on research conditions in the time of researches are not important.

Table 19: Grades for stormwater treatment facilities based on their performances

Treatment facility	Grades*						
	TSS	BOD_5	N^{tot}	P^{tot}	Metals	Bacteria	Oil/Grease
VBS	2, 3, 4	0	2, 3	2, 3	1, 2, 3, 4, 5	0	0
GS	5	1, 2, 3	4	4	0	5	5
EDP	5	3, 4	3, 4	4, 5	4, 5	0	0
CW	5	3, 4	3, 4	4, 5	4, 5	0	0
WP	5	0	2	4	4	5	0
IT	5	0	3, 4	4	5	5	0
IB	5	0	3, 4	4	4, 5	5	0
SF	5	4	4	4	0	4	4

* Somewhere there are multiple grades as some research results showed large variations in the purification processes

As it is obvious from table 19, the general overall grade can be given based only on smaller number of research sites or for different sites with same conditions as on the other hand variation of research result values is too pronounced. The best example of overall grade for removal efficiency parameters can be given for Wet Ponds as the results for this technology are individual and exact (there is no variations). This is presented in table 20.

Table 20: Evaluation of efficiency for Wet Ponds (WP)

Efficiency for Wet Ponds(%)						
TSS	BOD_5	N^{tot}	P^{tot}	Metals	Bacteria	Oil/Grease
80	N/A	27	59	51	93	N/A
Grades for Wet Ponds						
5	0	2	4	4	5	0

Land Requirements (physical feasibility) - LR

Next parameter that we will address to is called Land Requirements (LR) and it consists of many different factors such as soil properties (hydrological soil group), area requirements, applicability of certain treatment system to specific types of soil, etc. This parameter will be given as the function of other factors. Flow rate is extremely important parameter but is hard to compare as there is not enough data available for comparison. This parameter can be implemented as individual but will not be a part of analysis in this chapter.

According to International Stormwater Best Management Practices (BMP) Database (2010.) hydrologic soil group is the classification system for soils based on their hydrological properties, i.e. based on the infiltration of water after the soils have received precipitation from storm events. It is considered a first factor for land requirements and it can be distinguished in 4 different groups:

- A - soils that have a high infiltration rate (between 210 and 25 mm/h), i.e. low runoff potential; they usually consist of well to excessively drained sands or gravels, i.e. sand, loamy sand, sandy loam.
- B - soils that have a moderate infiltration rate between 25 and 13 mm/h; they consist of moderately well drained or well drained soils that have moderately fine to moderately coarse texture, i.e. sandy loam, loam.
- C - soils that have a slow infiltration rate between 7 and 4.5 mm/h; they consist of soils that have a layer that precludes any downward movement of water or soils that have moderately fine to fine texture, i.e. silty loam, sandy-clay.
- D - soils that have a very slow infiltration rate (between 2.5 and 0.5 mm/h), i.e. high runoff potential; they consist of clays that have a high shrink-swell potential, soils that have a permanent high water table, soils that have a clay pan or clay layer at or near the surface, and soils that are shallow over nearly impervious material, i.e. clay loam, sandy clay, silty clay, clay.

What is considered here is the applicability of certain technologies in relation to the hydrologic soil groups. Every technology has its limitations when it comes to application on terrain with certain characteristics. There are 3 grades and they are presented in table 21.

Table 21: Grades for applicability of technologies compared to soil type

Grade	Grade explanation
3	Treatment facility applicable for all types of soils
2	Treatment facility applicable for most soils but with additional requirements
1	Treatment facility applicable only for some soils and with severe requirements

Second factor of Land Requirements parameter is area required for construction of stormwater treatment facility. This factor is given as the percentage of overall catchment area and in rate for optimum functionality. Distribution of grades is shown in table 22 while in table 23 values of required areas for each treatment facility are viewed.

Table 22: Grades for area requirements

Grade	Area required
10	0-5%
8	5-10%
6	10-15%
4	15-20%
2	>20%

Table 23: Area required for construction of stormwater treatment facility (modified according to Young, 1996.)

Stormwater treatment technology	VBS	GS	EDP	CW	WP	IT	IB	SF
Area required	25%	10-20%	10-20%	10%	10-20%	2-4%	2-4%	2-3%
Grade	2	4, 6	4, 6	6	4, 6	10	10	10

Finally when all obtained results are gathered final table of grades for Land Requirements parameter can be made (table 24). It is noticeable that bigger grades are given to area requirement factor as this factor is, and compared to other factor, more limiting. Final score is obtained on the aggregation basis of relative ratings of individual factors important for the overall state of a particular basin, i.e. technology.

Table 24: Grades for Land Requirements

Area required	Applicability of technology	Aggregate ranges	Aggregate grade*
10	3	**11 - 13**	**5**
8	2	**9 - 10**	**4**
6	1	**7 - 8**	**3**
4	X	**5 - 6**	**2**
2	X	**3 - 4**	**1**

* If the treatment system has bigger area requirements only in the case where other factor is rated with best grade it can achieve best overall grade. Although this system may seem severe this is only generalization of system performances and further researches have to be conducted where system can eventually show better performances.

Cost Effectiveness

Cost Effectiveness is divided in two parts:

- Capital Costs (CC) and
- Operational/Maintenance Costs (O/MC)

Stormwater treatment facility cost information must be provided whenever possible because it is a basis for cost/benefit analysis of the technology. It should be provided so that investors and their investigators can conduct their analysis process. Costs vary among the individual devices, but for that very reason, the standardization of costs is made in order so that the same analysis factors can be applied to all treatments. In that way comparison for different potential treatment systems can be performed.

Capital Cost (CC) is the overall initial cost of the facility. It involves cost of original design, construction and installation of treatment facility and all associated costs (International Stormwater Best Management Practices Database, 2010). Capital Costs can be expressed in many different manners: compared to efficiency of pollutant removal, as overall aggregated sum or compared to catchment area for which treatment is used.

As a part of this evaluation system, and modified according to Corson (2006), the criteria for determining Capital Costs grades is made as a cost for stormwater treatment facility installed to treat stormwater from a 2 hectares site (table 25).

Table 25: Capital Costs according to treatment of stormwater from 2 ha site

Grade	Capital cost
5	$0 - $5000
4	$5000 - $10000
3	$10000 - $15000
2	$15000 - $20000
1	>$20000

Stormwater treatment facilities also require well controlled maintenance in order to work properly throughout their expected life. Operational/Maintenance Costs (O/MC) are usually presented as a percentage of Capital Costs and it is shown in table 26 (modified from Corson, 2006). In this evaluation system that is going to be just one factor of overall Operational/Maintenance grade (table 27). Other factors that are going to be considered are frequency of 'typical' maintenance (because some situations can require additional actions) and sediment removal in cases where certain part of retention or functional volume is lost (this requirement is individually prescribed for each system).

Table 26: Maintenance Costs expressed as percentage of Capital Costs

Grade	Meintenance Costs (%)
10	0 - 4
7	5 - 8
4	9 - 12
1	>12

Table 27: Grades for treatment facilities for maintenance costs (modified from EPA, 2006, Corson, 2006 and Caleb et al., 2006)

Stormwater treatment technology	VBS***	GS*	EDP**	CW**	WP***	IT***	IB*	SF*
Meintenance Cost (%)	5 – 7	5 - 7	3 - 5	3 - 5	3 - 6	5 - 20	1 - 10	11 - 13
Grade	7	7	10, 7	10, 7	10, 7	7, 4, 1	10, 7, 4	4, 1

* EPA, 2006

** Corson, 2006

*** Caleb et al., 2006

It is noticeable from this modified table of values for Maintenance Costs that best grades are given to Extended Detention Ponds, Constructed Wetlands, and Wet Ponds and in some cases even Infiltration Basins. Multiple grades are given because of the variations of research results which in that manner belong to several predefined classes (grades).

Frequency of 'typical' maintenance is a factor which covers frequency of main verifications of the system functionality such as visual check of aesthetic components, mowing and maintaining of vegetated areas, cleaning and removing debris after major storm events, maintenance of inlets and outlets, etc. It is expressed as time schedule for implementation of certain procedures. Grades for this factor are given in table 28 and from North Carolina Division of Water Quality.

Table 28: Grades for frequency of 'typical' maintenance

Grade	Frequency
5	Annualy or more
4	Every 6 months
2	Less than 6 months

Last factor for determining Maintenance Costs parameter is sediment removal as the special separate paragraph. It is important as it has to be performed in longer time periods and separately from other maintenance checks and actions. Main characteristic is that it is performed in the cases where certain part of functional volume of the stormwater treatment facility is lost. The percentage of lost volume is determined individually for each facility and it is not part of this evaluation system. The ranges for each grade for this factor are modified according to EPA (2006) and are shown in table 29 and grades of stormwater treatment facilities for this factor are given in table 30.

Table 29: Grades range for sediment removal frequency for stormwater treatment facilities

Grade	Frequency
3	Not needed
2	5 years and less
1	More than 5 years

Table 30: Stormwater treatment facilities grades for frequency of sediment removal

Stormwater treatment technology	VBS	GS	EDP	CW	WP	IT	IB	SF
Frequency	Not needed	~ 5 years	5 - 20 years	5 - 20 years	5 - 20 years	4 years	3 - 5 years	3 - 5 years
Grade	3	2	1	1	1	2	2	2

Finally, when all the factors are explained and reviewed the final table for Operational/Maintenance Costs (O/MC) can be formed. It is consisted of grades from 5 to 1, like all the other parameters. Because of more factors involved each grade is presented as the range of sum of grades for consisting factors. The final grades are presented in table 31.

Table 31: Grades for Operational/Maintenance Costs for stormwater treatment facilities

Grade	Sum range
5	18 - 16
4	15 - 13
3	12 - 10
2	9 - 7
1	6 - 4

If needed researches were conducted and all the data collected, evaluation system would be able to provide a general picture of possible treatment facilities for certain situation. Graphically, grades are shown as a radar system where overall general pictures of all systems, which are potential solutions, can be compared in order to issue the best solution. An example of graphical view for two possible technologies is shown in figures 45 and 46 (on figure 47 graphical comparison is introduced) which are, just for the purpose of explanation of the system, based on fictional data (table 32).

Table 32: Grades for two fictional systems: Wet Pond and Infiltration Trench

Treatment facility	**Grades**									
	TSS	BOD_5	N^{tot}	P^{tot}	Metals	Bacteria	Oil/Grease	LR	CC	O/MC
WP	5	0	2	4	4	5	0	3	2	4
IT	5	0	4	4	5	5	0	4	2	3

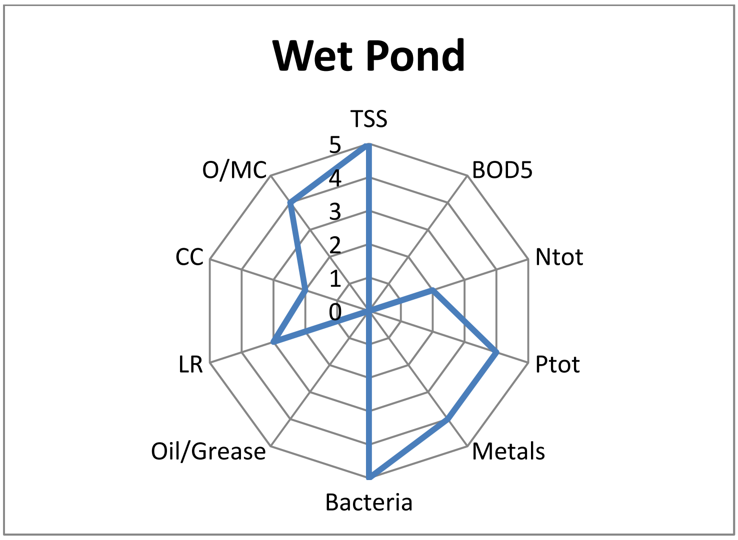


Figure 45: Graphical view of evaluation grades for Wet Pond

Explanation of abbreviations:

TSS - Total Suspended Solids

BOD_5 - Biological Oxygen Demand in 5-day period

N^{tot} - total amount of Nitrogen

P^{tot} - total amount of Phosphorus

Metals - heavy metals (all or copper, zinc, lead and/or cadmium as the relevant ones)

Bacteria - Pathogens

Oil and Grease - hydrocarbons

LR - Land Requirements

CC - Capital Costs

O/MC - Operational/Maintenance Costs

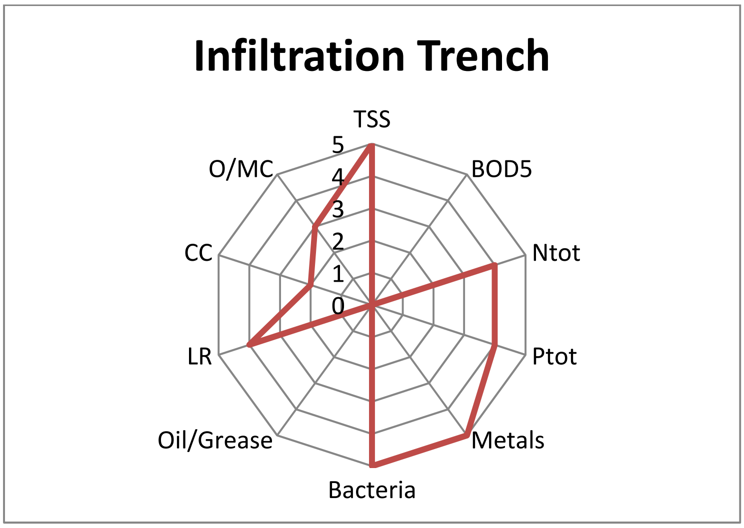


Figure 46: Graphical view of evaluation grades for Infiltration Trench

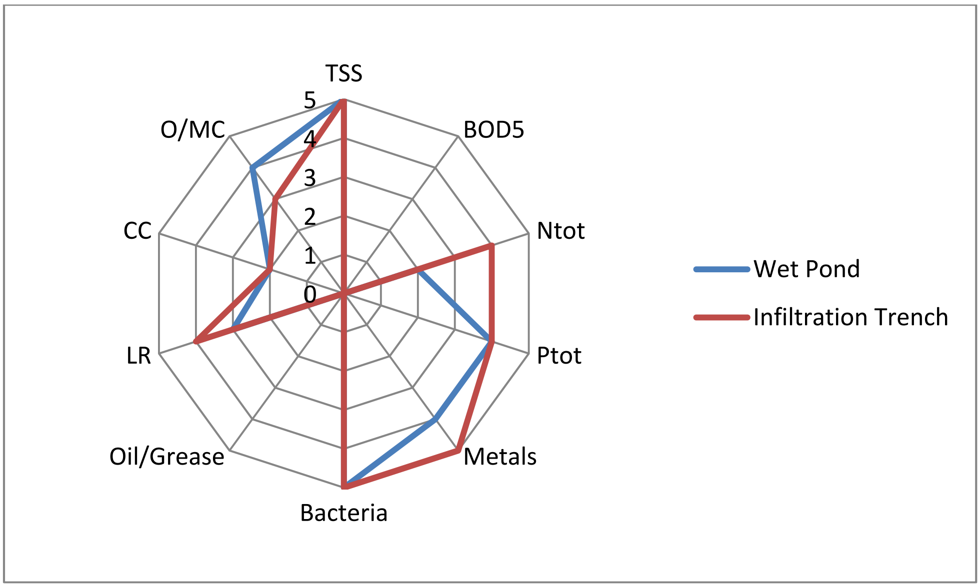


Figure 47: Graphical comparison of possible solutions, i.e. treatment systems

6.2. Recommendations for future development of Croatia

Management of stormwaters from roads and highways is extremely important in terms of protecting drinking water sources. In Croatia, primary 'action' for conservation of water sources is determination of sanitary protection zones which was already explained closely in chapter 4.

Detailed analyses of catchment area characteristics are basis for determination of these zones. Their lists (of needed analysis) as well as the rules for conducting them are prescribed by certain laws. When it comes to sources in fine grained porosity soils and the catchment of water from reservoirs, lakes and open watercourses current guidelines should be sufficient enough and classic pollution protection can be applied. That is not the case with sources that are found in cracking and cracking-cavernous porosity soils (karst areas). Karst is characterized by extreme underground hydrological network, high groundwater flow speed potential, small surface runoff and small possibility of autopurification.

Given the sensitivity of these areas, protective procedures must be systematically monitored and maintained. Croatian area is covered with karst in about 52%, which represents a major challenge for the responsible structures when it comes to protecting water quality. If the protection of such zones was carried out literally according to requirements, it would mean that the entire area would be declared a protection zone. Such action would prevent any kind of economic development in the region which is not of overall interest. Also, protection zones from many different sources overlap with each other or share a same border, which means that in certain places even if criteria would be more lenient, it would be possible to set new routes. Such regime would also imply the removal of all existing potentially harmful structures.

Recommendations will be divided into two parts:

- for sources in fine grained porosity soils and from reservoirs and lakes
- for cracking and cracking-cavernous porosity soils (karst areas).

6.2.1. Sources in fine grained porosity soils and from reservoirs and lakes and open watercourses

Sanitary protection zone III

Storm water should be treated through two levels of purification:

- with Oil/Grit Separator,
- and with treatment facility consistent with the characteristics of catchment area and pollution loads.

I f space limitation exists stormwater should be treated with Oil/Grit Separator in combination with Sand Filter, where Separator removes oils and fats and part of larger fragments and Sand Filter removes other important contaminants but with limited efficiency. If there is no space limitation stormwater should be treated with Oil/Grit Separator in combination with a system of higher efficiency (Vegetated Buffer Strips (Filter Strips), Grassed Swale, Extended Detention Ponds, Constructed Wetlands, Wet Ponds, Infiltration Trenches, Infiltration Basins), and in accordance with the 'in situ' characteristics. The difference between the Sand Filters and other treatments in terms of efficiency is based on the study of results from different researches on the efficiencies of these systems.

If the above mentioned systems are not applicable (due to certain requirements or limitations) stormwater should be collected and taken outside protection zone by enclosed and impermeable draining system. There it should be treated (treatment is selected according to characteristics of the area) and disposed in the surrounding soil or other receiver.

In order to avoid the risk of accidental contamination and to reduce pollutants loads, following non-structural measures should be taken: stricter traffic speed limitations, diversion of transportation of hazardous substances to less vulnerable areas, regular controls, determine severe legal penalties in case of violation of the prescribed measures (fines determined in relation to the assumed cost of rehabilitating possible contamination).

Sanitary protection zone II

In sanitary protection zone II for sources in fine grained porosity soils, in order to avoid contamination, stormwater should only be collected and taken outside protection zone by enclosed and impermeable draining system. There it should be treated (treatment is selected according to characteristics of the area) and disposed in the surrounding soil or other receiver.

For sources from reservoirs and lakes the same recommendations as in sanitary protection zone III should be applied.

Also the same non-structural measures as in sanitary protection zone III should be applied for all (above mentioned) types of catchments.

Sanitary protection zone I

In protection zone I all activities except those related to drinking water manipulation, are prohibited. This also means that highways can’t be built in these zones. In relation to these restrictions, recommendations for treatment of stormwater from highways are not necessary.

6.2.2. Sources in cracking and cracking-cavernous porosity soils (karst areas)

Sanitary protection zone IV

Treatment of collected stormwater should be carried out through 2 treatment stages. First, water should be taken to Oil/Grit Separator, and then to secondary treatment facility. For secondary treatment Extended Detention Ponds, Constructed Wetlands or Wet Ponds (with geosynthetic or clay liner) can be used. Also Sand Filters can be used and due to easy combination with Oil/Grit Separator (in many cases Sand Filter is added as an additional chamber in the Oil/Grit Separator). Given lower pollutants removal efficiency, at the end of such system Vegetated Buffer Strips should be used to ensure the quality of treated water as well as non-concentrated disposal of water into receiving soil. In these types of soils (karst areas) use of Infiltration Trenches and Infiltration Basins should be banned because of the concentrated flow that is typical for them and which can cause negative effects.

Optimal system for treatment of stormwater from highways in protection zone IV is composed of Oil/Grit Separator (removes oil and grease and part of coarse particles), Extended Detention Pond (minimum maintaining requirements; can be used during dry seasons; very good pollutants removing efficiency) and a system for dispersed disposal of purified waters (grassed channels or trenches).

Sanitary protection zone III

Collected stormwater should be taken outside of protection zone III by closed drain system. It should be taken either to the treatment facilities in protection zone IV or completely outside the protected zones.

As an exception, stormwater should be treated in protection zone III with system recommended for treatment in protection zone IV only if regularly road flushing is conducted. If cleaning is not conducted during dry periods that are typical for this region, deposited pollutants have potential to achieve critical concentrations.

Sanitary protection zone II

Collected stormwater should be taken to the treatment facilities in protection zone IV or completely outside the protected zones by closed drain system. This system has to be regularly and strictly controlled as possible contamination of underground in this protection zone leads to severe consequences for water quality at the source.

Sanitary protection zone I

In protection zone I all activities, except those related to drinking water manipulation, are prohibited. This also means that the construction of highways or any other transportation system is strictly forbidden. In relation to these restrictions, recommendations for treatment of stormwater from highways are not necessary.

In sanitary protection zones for water sources in cracking and cracking-cavernous porosity soils non-structural measures listed in section 6.2.1. should also be applied.

With respect to the physical features of karst terrain systematic protection of groundwater should not be limited only to the source protection zones which is the current situation in Croatia. This problem can be solved by introducing the apparent sanitary protection zone V, which would act as a set of rules for the treatment of stormwater out of direct water protection zones. This would ultimately lead to a grouping of legal regulations in one place which would lead to better implementation, as well as better control from the competent authorities. In that way the legal obligation would easily become part of the mandatory practices. Current common practice in Croatia for treatment of stormwater outside the protected areas is usage of individual Oil/Grit Separators (which is not legally binding), although their effect is limited to the removal of oils, fats and part of coarse solid particles. Oil/Grit Separators are efficient enough only in combination with other treatments so treatments such as Extended Detention Ponds, Wet Ponds and others should be regarded as optimal ones and according to environment requirements.

Design of a treatment facility should be approached from a detailed analysis of the environment in which system is planned. Basic characteristics of the basin should be considered as a starting point for primary selection of potential solutions. After first step, evaluation system proposed in section 6.1. should be used for further selection. Finally after narrowing selection, detailed studies should be conducted for potential solutions in order to decide on the optimal one.

6.2.3. Monitoring

Monitoring of stormwaters in Croatia is not developed to a sufficient level. Responsible structures are currently working on the harmonization of Croatian standards with European ones in order to achieve the required quality.

Monitoring of quality of stormwater prior to construction of the road, i.e. prior to anthropogenic impacts on the environment should be conducted for a specified period as well as the assessments of water quality deterioration due to construction of road system. Measurements should be made during at least 4 events: 2 during the rainy period and 2 after the drought.

Terms for the definition of rainy and dry periods have to be defined later on by experts and based on specific characteristic for different regions or on the national basis.

Although each site has different and specific values, the results of monitoring can serve as a basic criterion in selecting the optimal treatment system of stormwater for a location with approximately similar characteristics (from hydrological, geological and hydrogeological point of view). For conducting such system central office (by state administration) should be organized. It would collect all monitoring data for different locations as well as finally selected treatment systems and the criteria by which they were selected.

In that way easier control of rendered systems would be possible and based on the recorded data systems of primary importance would be determined. This would also allow better control of the general conditions of critical systems. On the other hand data archive would be created and it would eventually give the general state of stormwater drainage in Croatia, which could serve as good foundation for further development of drainage systems and quality control of water supply.

7. CONCLUSION (DISCUSSION OF THE RESULTS AND FUTURE RESEARCH)

Task of this thesis was to show the general legal and technological characteristics in terms of management of stormwater from highway in 4 countries: USA, Germany, Switzerland and Croatia. Specifically, the task was to transfer positive settings from developed countries (Germany, USA, Switzerland) on the less developed one (Croatia) and to develop recommendations for further development of its highway system.

In chapter 2 basic precipitation data analysis was conducted for each country, and also a brief review of highway systems and pollutants that are found in stromwater in these systems. From figure 10 we can see that the USA has the highest average annual precipitation (1080 mm) while Germany has the lowest one (603 mm). Also in final part of the chapter, in table 6 we can see main pollution sources and their parameters.

Chapter 3 was dedicated to legislation analysis. Given all the major legislations from each country and their comparison it was concluded that Croatian regulations and obligations are not sufficent enough when it comes to stromwater management. At this moment Croatia is on the doorstep of European Union whose full member will become in 2013. From this perspective, responsible experts are currently working on the harmonization of laws, which should ensure better quality control and general handling of stormwater from highways.

Next the situation in Croatia was described and as a part of chapter 4. Due to the specific geology, which includes about half of the area being of karst origin, exactly the karst is imposed as the greatest problem of stormwater drainage on the Croatian territory. As following, in figure 20 further planned development of the Croatian highway system was shown, which could hardly be met by the deadline due to current economic situation in Croatia and Europe. In final part of the chapter we looked into sanitary protection zones of drinking water sources as this system provides us with basic limitations that have to met when it comes to treatment and disposal of stormwater from road systems.

In chapter 5 state of the art of stormwater treatment facilities was discussed. The facilities that were presented in this part are most commonly used systems when we look at the overall situation in all the countries. Although both natural and technical based treatments were discussed, emphasis was later on placed on natural ones because they are optimal in terms of sustainable development. They minimally interfere with nature, and if well maintained their efficiency is extremely high, as well as their lifetime. In final part of this chapter an insight into performances of this systems was given which was used as a basis for evaluation system presented in chapter 6.

The evaluation system is just a first step towards quality decision for stormwater treatment. It can be used for primary classification of potential solutions, where general picture of systems is presented as a basis for the initial selection. This can greatly reduce the cost of possible future researches because it limits the number of potential solutions.

In the last part of the chapter recommendations for future development of Croatian road system were given. They are based on introduction of additional zones of protection as well as stricter criteria in the existing ones. Better and more regular monitoring is recommended, before performing the procedure but also during operation of the building and the establishment of a central office for storage of monitoring data as well as the results of environmental impact studies which would create a quality environment for further progress and catching up with the situations in more developed countries. Special emphasis is placed on karst regions as they are very sensitive when it comes to transport of pollution where they can transport it to various distances without possibility of control.

Quality and controlled drainage of stormwater wasn't geting too much attention in the past. This is changing due to increasing public awareness. Many laws are slowly being accepted and it's only a matter of time when they are going to be fully implemented. Governing structures must ensure regular checks and severe punishments so that all stakeholders adhere to the rules. In developed countries, such practice has already been enthroned and now it is slowly spreading to less developed countries. In this lies the importance of projects like MASH.

In underdeveloped countries various interests of different structures cause a mismatch between prescribed and performed procedures. Conflicts arise because of different views, and major are politics, capital, public interest and expertise. Main reasons for poor quality of the management of highways are:

- failure to follow the results of professional work of researchers,
- bad laws and regulations and
- weak controls.

This paper points to the need to take additional efforts and activities in water protection within the sanitary protection zones of drinking water sources. That means that quality treatment of stormwater and improved monitoring of water quality conditions should be secured.

Finally, future development of Croatia can be secured only if:

- better monitoring programs and environmental impact studies are secured;
- individual aproach to every site is conducted;
- more sever regulations are prescribed.

8. SOURCES

Legislatives

- 2000/60/EC, European Water Framework Directive, 2000

- 814.20, Federal Law on the Protection of Waters (Switzerland), 1993

- 814.201, Water Protection Ordinance (Switzerland), 2000

- Federal Water Pollution Control Act, 2002 (USA)

- Safe Drinking Water Act, 1996

- Clean Water Act, 1972

- (OG22/86) Pravilnik o zaštitnim mjerama i uvjetima za određivanje zona sanitarne zaštite izvorišta vode za piće (Regulations on safety measures and conditions for determination of sanitary protection zones of drinking water sources), 1986

- (OG 110/07) Zakon o zaštiti okoliša (Environmental Protection Act), 2007

- (OG 130/11) Zakon o vodama (Water Act)

References

- Arturo A. Keller, Jenny Phillips, Reni Keane-Dengel: Cost and Effectiveness of Stormwater Treatment Technologies, 2008. (web article in Stormwater – the journal for surface water quality professionals)

- Barrett, M.; Lantin, A.; Austrheim-Smith, S.: Stormwater Pollutant Removal in Roadside Vegetated Buffer Strips, no year

- Becouze,C., J.-L. Bertrand-Krajewski, A. Dembélé, C. Cren-Olivé, M. Coquery: Preliminary assessment of fluxes of priority pollutants in stormwater discharges in two urban catchments in Lyon, France, no year

- Boller, M.: Towards sustainable urban stormwater management, Swiss Federal Institute for Environmental Science and Technology

- Caleb Arika, Dario J. Canelon, John L. Nieber and Robert D. Sykes: Impact of Alternative Storm Water Management Approaches on Highway Infrastructure: Guide for Selection of Best Management Practices - Volume 1, University of Minnesota Department of Landscape Architecture, 2006

- California Stormwater Quality Association (CASQA): California Stormwater BMP Handbook for New Development and Redevelopment, 2003

- Corson, L.A.: Assessment and Selection of Stormwater Best Management Practices for Highway Construction, Retrofitting , and Maintenance, Indiana, 2006

- Crnjak, M., Puž, G.: Kapitalna prometna infrastruktura Republike Hrvatske, Hrvatske Autoceste, 2007

- Croatian Bureau of Statistics: Census of Population, Households and Dwellings 2011, First Results by Settlements, Zagreb, 2011

- Environment agency: Sustainable Drainage Systems (SUDS)

- EPA: National Management Measures to Control Nonpoint Source Pollution from Urban Areas, November 2005

- EPA: Options for expressing daily loads in TMDLs, June 2007

- EPA: Managing Urban Stormwater: Treatment Techniques, 1997

- E. Erikssona, A. Bauna, L. Scholesb, A. Ledina, S. Ahlmanc, M. Revittb, C. Noutsopoulosd, P.S. Mikkelsena: Selected stormwater priority pollutants — a European perspective, June 2007

- EUROPEAN COMMISSION: PROGRESS REPORT ON CROATIAN FOR THE YEAR 2010, Bruxelles, 2010

- Fleury, S.: Land Use Policy and Practice on Karst Terrains - Living on Limestone, Florida, 2009

- Hall, D.; Lanz, K.; Lobina, E.; de la Motte, R.: Water time (research project), 2004, European Commission

- Hrvatska Udruga Koncesionara za Autoceste s Naplatom Cestarine (Croatian Association of Toll Motorways Concessionaires): Ključne brojke 2011 (Key Numbers 2011), Zagreb, 2012

- LeChevallier, M. W., Au, Kwok-Keung: Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water, London, UK, 2004 (World Health Organization)

- Loncar, N.: Zaštita izvora pitke vode u kršu (Protection of sources of drinking water in karst), 2010

- Malus, D.: Studija odvodnje prometnica (Study drainage roads), Građevinski fakultet sveučilišta u Zagrebu, (Faculty of Civil Engineering, University of Zagreb), no year

- Margeta, J., Fistanić, I., Šarić, M.: Procjena zagađenja od oborinskih voda u krškim područjima (Assessment of pollution from stormwater in karst areas), GRAĐEVINAR (Civil engineer) 54, 2002, pp. 265-274

- NCHRP, report 565: Evaluation of Best Management Practices for Highway Runoff Control, Washington, 2006

- Ožanić, N.: Engineering hydrology, internal script of Faculty of civil engineering in Rijeka, 2012.

- Paul Schiariti, P.E: Basic Hydrology Tr-55 vs. MRM By, CPESC Mercer County Soil Conservation District, no year

- Peter T. Weiss, John S. Gulliver, Andrew J. Erickson: Cost and Pollutant Removal of StormWater Treatment Practices, Journal of water resources planning and management, ASCE, May/June 2007

- Pfeffermann, A.L.: Management of Stormwater on Highways - Master thesis, Wiesbaden, 2011

- Pitt, R., Narayanan, A.: Costs of Urban Stormwater Control Practices, Alabama, 2006

- Robert Y.G. Andoh - Vortex Separators Provide Various Options in Grit Removal (Article), 2011

- Rubinić, J.: Krš - Pojam, definicije i terminologija (Karst - Term, definitions and terminology), internal script of Faculty of civil engineering in Rijeka, no year

- Sänkiaho, L.: Metals in stormwater pollution, Helsinki, 2009

- Schmollinger, K.: Management of Stormwater on Highways - findings on traffic-related pollutants, selection of appropriate treatment methods and monitoring - Interdiciplinary Project, Wiesbaden, 2012

- Swiss Confederation (FOEN; FOPH): Reporting for Switzerland under the Protocol on Water and Health, no year

- Urbonas, B.: Assessment of Stormwater Best Management Practice Effectiveness, no year

- - Vermont, S.: National report of Switzerland on the role of ecosystems as water suppliers, Swiss Agency for the Environment, Geneva, December 2004

- Vlahović, I.: Comparison of the Croatian legislation with EU directives on the protection of inland waters, Zagreb, 2010

- Washington State Department of Transportation: Highway Runoff Manual, 2011

- Washington State Department of Ecology: Stormwater Management Manual for Western Washington, Volume V: Runoff Treatment BMPs, Washington, 2005

- Washington State Department of Ecology: Stormwater Management Manual for Western Washington, Volume V: Runoff Treatment BMPs, Washington, 2005

- Wright Water Engineers, IncGeosyntec Consultants, Inc.: International Stormwater Best Management Practices (BMP) Database: BMP Performance Data Summary Table, November 2011

- Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank: Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032, Federal Highway Administration, 1996

Online sources

- [[1]; 29/03/2012] http://www.lca.org.mt/pages/iseSinglePages.asp?m=152

- [[2]; 31.03.2012.] http://www.kingcounty.gov/environment/waterandland/shorelines/program-update/shoreline-ecology/hydrologic-cycle.aspx

- [[3]; 31.03.2012.] http://shoalwater.nsw.gov.au/education/precipitation.htm

- [[4]; 02.04.2012.] http://www.bestcountryreports.com/

- [[5]; 04.04.2012.] http://www.climatetemp.info

- [[6]; 05.04.2012.] http://en.wikipedia.org/wiki/Highway

- [[7]; 05.04.2012.] http://upload.wikimedia.org/wikipedia/commons/thumb/2/2c/Autocesta.svg/500px-Autocesta.svg.png

- [[8]; 10.04.2012.] http://www.nrdc.org/water/pollution/storm/chap2.asp

- [[9]; 12.04.2012.] http://www.northgeorgiawater.com/images/stormwater_pollution_3.JPG

- [[10]; 22.04.2012.] http://www.epa.gov/lawsregs/laws/cwa.html

- [[11]; 22.04.2012.] http://water.epa.gov/lawsregs/guidance/sdwa/upload/2009_08_28_sdwa_fs_30ann_sdwa_web.pdf

- [[12]; 28.04.2012.]

http://www.eea.europa.eu/soer/countries/ch/soertopic_view?topic=freshwater

- [[13]; 28.04.2012.] http://www.coralreef.gov/transportation/evalbmp.pdf

- [[14]; 18.05.2012.] http://www.thewatertreatments.com/water-treatment-filtration/filters/

- [[15]; 24.05.2012.] http://open.jorum.ac.uk/xmlui/bitstream/handle/123456789/1015/Items/T210_1_section24.html

- [[16]; 26.05.2012.] http://www.leiblein.com/images/stories/prozesswasser/lamella-separator-principle.jpg

- [[17]; 26.05.2012.] http://www.gea-2h.co.uk/images/lamellasep2.jpg

- [[18]; 26.05.2012.] http://info.grad.hr/!res/odbfiles/1823/predavanja/1.7-pi.pdf

- [[19]; 26.05.2012.] - Hydro International - online broschures, 2012. http://hydro-international.biz/us/index.php

- [[20]; 27.05.2012.] http://www.lenntech.com/membrane-technology.htm

- [[21]; 01.06.2012.] http://www.hr/hrvatski

- [[22]; 02.06.2012.] http://www.cromaps.com/assets/opci_podaci/opcikartaklimacromaps.jpg

- [[23]; 03.06.2012.] http://www.mppi.hr/UserDocsImages/Copy%20of%20CORE_NETWORK_2009_2020%20II.pdf

- [[24]; 04.06.2012.] http://www.geografija.hr/clanci/1011/rasirenost-krsa-u-hrvatskoj

- [05.04.2012.] http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/stormwater_discharge_final.pdf