ROad runoff Pollution management and mitigation of environmental Risks

PROPER PROJECT
WP1 – PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF
Task 1.1. Literature review on road runoff pollution on Europe

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Title

PROPER PROJECT - WP1.PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF
Task 1.1. Literature review on road runoff pollution on Europe

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PROPER PROJECT - WP1.PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF

T1.1. Literature review on road runoff pollution on Europe

Abstract

This report stands for the project deliverable 1.1 and concerns the results from task 1.1 of the PROPER Project, namely *literature review on road runoff pollution on Europe*.

This review presents the most relevant literature references on road runoff pollution and was mainly focused on references published since the year 2000. It aims at identifying the most important pollutants in road runoff – key pollutant – and having an overview of concentrations and pollutants loads in road runoff across Europe. An evaluation of the relationships between the road runoff characteristics, the road site and the event characteristics is undertaken as a foundation for tasks 1.3 and 1.4 of PROPER Project. References with monitoring data or prediction tools of road runoff pollution with interest in the European context are also included. One of the objectives is to get an updated and general overview of existing data.

A *reference matrix* was constructed to help the assessment of the literature references. All partners contributed to fill it in. A total of 103 literature references were analysed, comprising 48 scientific papers, 31 technical reports, 9 conference proceedings and 15 other documents. After the assessment of the literatures, it was considered that the review was consistent and provided the needed information and background for WP1 activities.

In addition to this main output, this report also presents the established structure for the *database matrix*, designed to gather road runoff monitoring data from different case studies. This matrix includes all the variables relevant for the study under WP1, such as key pollutants, and local characteristics and will be filled by all partners with relevant monitoring data on task 1.3.

Keywords: Data collection, literature review, prediction, modelling, road runoff pollution

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1 | Introduction

The project PROPER is funded by the Conference of European Directors of Roads (CEDR) and it comprises the characterisation and prediction of road runoff pollution, an evaluation of its potential impacts on receiving water bodies and related ecosystems, and an evaluation of treatment systems for impact mitigation during operation and construction of roads. The project has a total duration of 24 months and has started in September 2017.

The work programme is organised into 6 major Work Packages (WPs) where WPs 1 to 4 correspond closely with the scientific objectives of the project, namely:

- **WP1:** Prediction of pollutant loads and concentrations in road runoff;
- **WP2:** Assessing the vulnerability of European surface and ground water bodies to road runoff during the building and operating of roads;
- **WP3:** Sustainable assessment of measures and treatment systems for road runoffs;
- **WP4:** Sustainable assessment of measures and treatment systems for road runoffs during construction work.

WP5 focuses on ensuring maximum impact is achieved through the implementation of a robust dissemination strategy with **WP6** outlining the project management activities which underpin successful project completion.

This report stands for the project deliverable 1.1 and concerns the results from task 1.1 of the Project PROPER namely literature review on road runoff pollution on Europe. This task finalizes this output.

This review presents the most relevant literature references (*e.g*. scientific papers and reports) on road runoff pollution and it was mainly focused in references published since year 2000. It aims at identifying the most important pollutants in road runoff referred to as key pollutant and having an overview of concentrations and pollutants loads in road runoff across Europe.

An evaluation of the relationships between the road runoff characteristics (*e.g*. concentrations, loads), the road site (*e.g*. traffic volume, land use) and the event characteristics (*e.g*. rainfall volume, intensity) is undertaken as a foundation for tasks 1.3 and 1.4. References with monitoring data or prediction tools of road runoff pollution with interest in the European context are also included. One of the objectives is to get an updated and general overview of existing data.

A *reference matrix* was constructed to help the assessment of the literature references. All partners contributed to fill it in with respects to the literature references they have reviewed. A total of 103 literature references were analysed comprising 48 scientific papers, 31 technical reports, 9 conference proceedings and 15 other documents.

Moreover, the structure of the *database matrix* to gather road runoff monitoring data from different case studies was defined. This matrix includes all the variables relevant for the study, such as key pollutants, and local characteristics and will be the basis for the selection of representative sites across Europe

which is planned for task 1.3. At this stage, in the scope of the WP1, the objective was also to establish a standard procedure for data collection, which can be applied by other partners where this is appropriate.

After this introduction section, the objectives and methods of this literature review are presented in section 2, and a critical overview of the references is presented in section 3.

The assessment of the selected relevant references is presented in section 4. After a standard assessment of the literature references, the most common pollutants are identified. The most relevant references regarding monitoring and modelling studies are assessed. Finally, following the assessment of the selected relevant references, a tentative characterization of patterns of road runoff pollution is provided.

2 | Objectives and methods

A consistent and updated understanding of road runoff pollution characteristics in Europe is the main objective of the current deliverable/report. This characterization is made by a literature review with the aim of having a state-of-the-art description of the main road runoff pollutants in the European context. After the evaluation of the most common pollutants in road runoff, this report is dedicated to the pollutant characterization in terms of concentrations and loads and the methods or tools for their prediction.

An evaluation of the relationships between the road runoff characteristics (*e.g*. concentrations, loads), the road site (*e.g*. traffic volume, land use) and the event characteristics (*e.g.* rainfall volume and intensity) is undertaken as a basis for the following tasks of WP1 of the PROPER Project.

The literature references of monitoring data or prediction tools of road runoff pollution with focus on the European context are included in the *reference matrix* created within WP1. The method used to conduct the literature review is schematically explained in Figure 1.

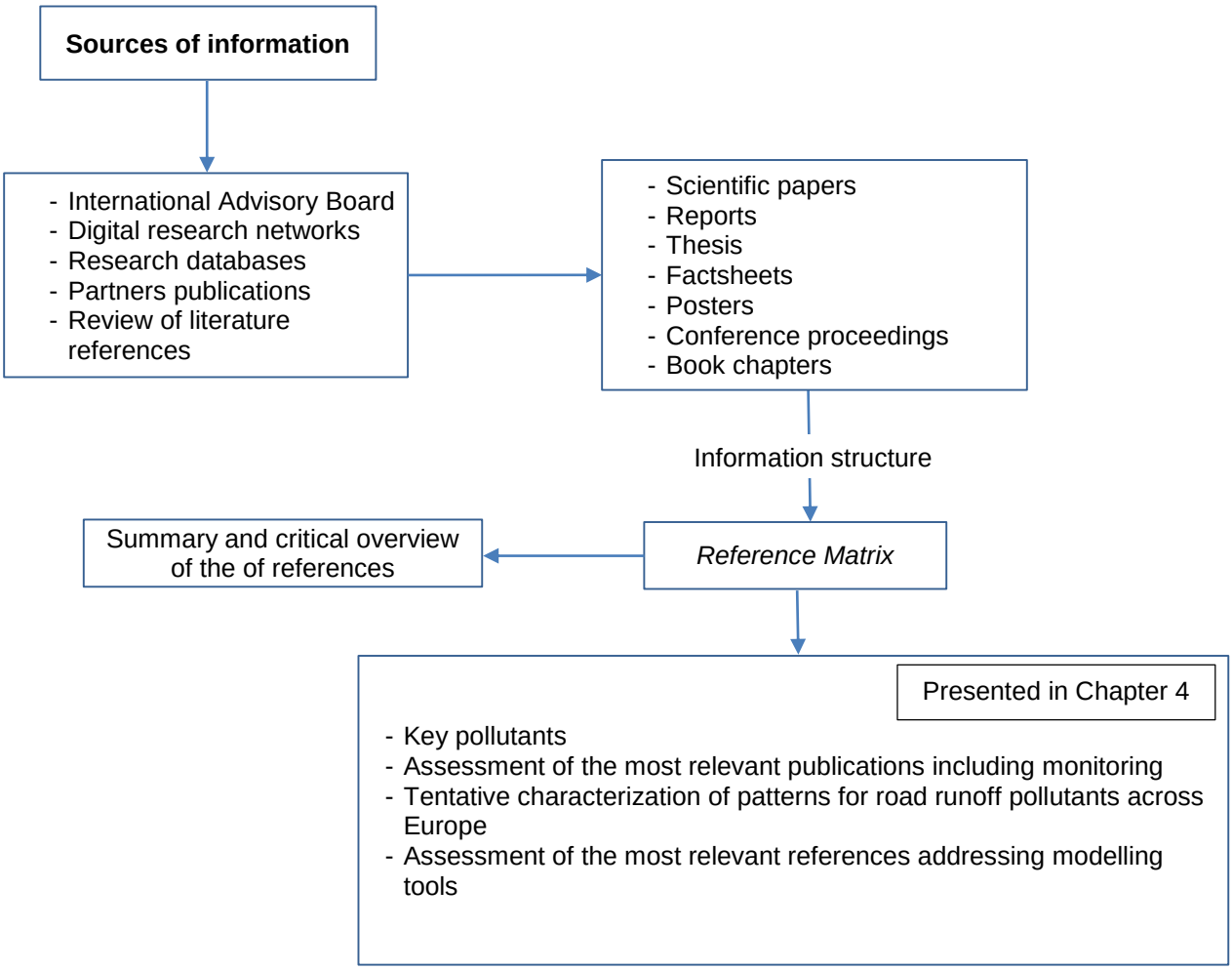

Figure 1. Procedure followed for the literature review.

The literature review started with the identification of the sources of information where recent and relevant studies may be found. The sources of information are presented herein.

- Contacts with the IAB: During the IAB meeting (Cologne, Germany, 18th October 2017) the members of the IAB were asked to present their activity. From this meeting, specific publications have been pointed out and are included in the present literature review.
- Research search tools such as Scopus and Science Direct.
- Digital research networks such as research gate (https://www.researchgate.net/) or research ID (http://www.researcherid.com).
- Project partner publications.
- National reports in their countries and in neighbouring countries were collected by all partners.

From these sources of information, references were selected namely research papers, conference proceedings, national or international guidelines or reports from environmental agencies and national road administration and operators.

The following criteria were applied to the selection of the references:

- references relevant to the WP (*i.e.* dealing with characterization of road runoff pollution);
- references should be recent (preference for publications after year 2000), exceptions may be conceded to relevant studies;
- references important for the European context.

The next step was to organize the collected references. To do that, a *reference matrix* was constructed. The draft of the matrix was presented at the research team meeting (Cologne, Germany, 17th October 2017) and all partners contributed to its final version.

This *reference matrix* helped to uniform the data collection and hence the analysis of the information. The entries of the matrix and their reasoning are explained in the following paragraphs.

Each reference is identified by its **bibliographic record** (title, authors, source), **type** (scientific *paper*, *conference proceeding*, *thesis* - PhD or MsC, *report*, conference *poster*, *Book* or *Factsheet*), **year** of publication and **language**.

The aim of the study is also included namely if comprises **monitoring**, **modelling** and the assessment of the **vulnerability** of the receiving water body.

If the reference includes monitoring, the **characteristics of the site** where the study took place are described in terms of weather conditions, road characteristics, etc.

Each reference has a **resume** and the main **conclusions** (as 250 words of text each), written by the person that selected the publications to be included in the *reference matrix*.

Lastly, the importance of the reference to the project is evaluated according to the following scale:

1 – Poorly relevant;

2 – Relevant;

3 – Relevant with monitoring data;

4 – Relevant with data and modelling;

5 – Highly relevant.

After filling the reference matrix, the assessment of the references was performed regarding the most common key pollutants and tentative characterization road runoff pollution. The most relevant references with monitoring data and modelling tools are assessed in detail in sections 4.3 and 4.5, respectively.

3 | Critical overview of the references

Based on databases, the expertise of the partners and the inputs from the PEB and IAB members, a total of 103 literature references were selected. After this listing, the seven partners contributed to the analysis by filling in the matrix with the most important information (as described in the previous section).

Figure 2 presents the number of references per type of publication.

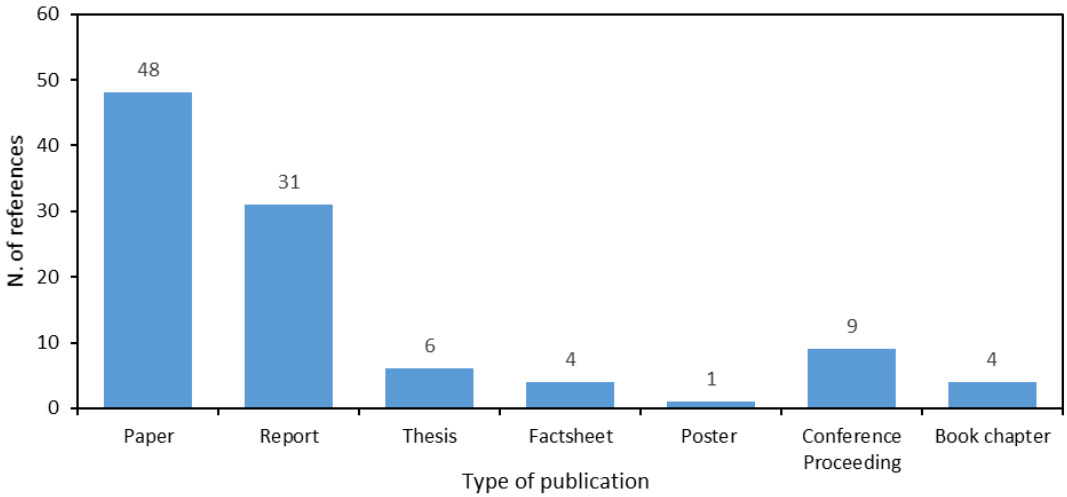

Figure 2. Frequency of the references regarding the type of publication.

As expected, the most common types of publications are scientific papers and reports. They represent almost 80% of the total number of references.

Figure 3 presents the frequency of the literature reference regarding the year of publication. As stated in the proposal, the references are rather recent. Only 8 of the 103 references are from the 1990's. Years 2003, 2007, 2016 and 2017 are the most represented, corresponding to about 37% of the total.

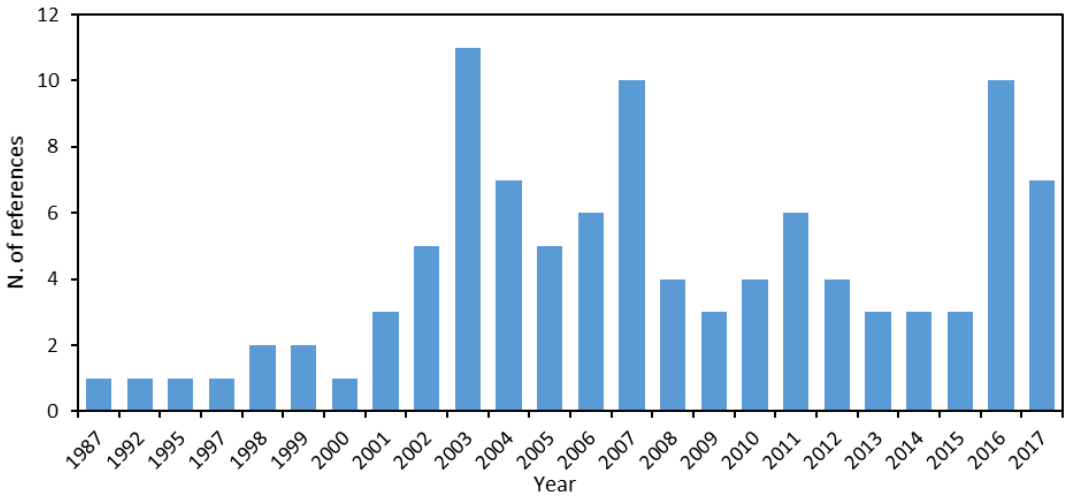

Figure 3. Frequency of the references regarding the year of publication.

The various languages of the 103 publications are evaluated in Figure 4.

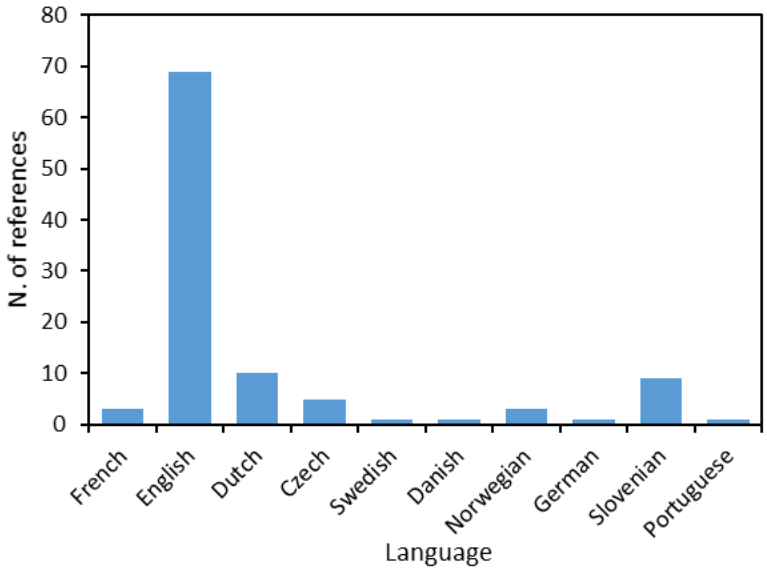

Figure 4. Frequency of the references regarding the language.

As expected, the most frequent language is English as it is the most common language used to share knowledge in the scientific community.

Figure 5 presents the frequency of the references regarding the country where the monitoring field work took place.

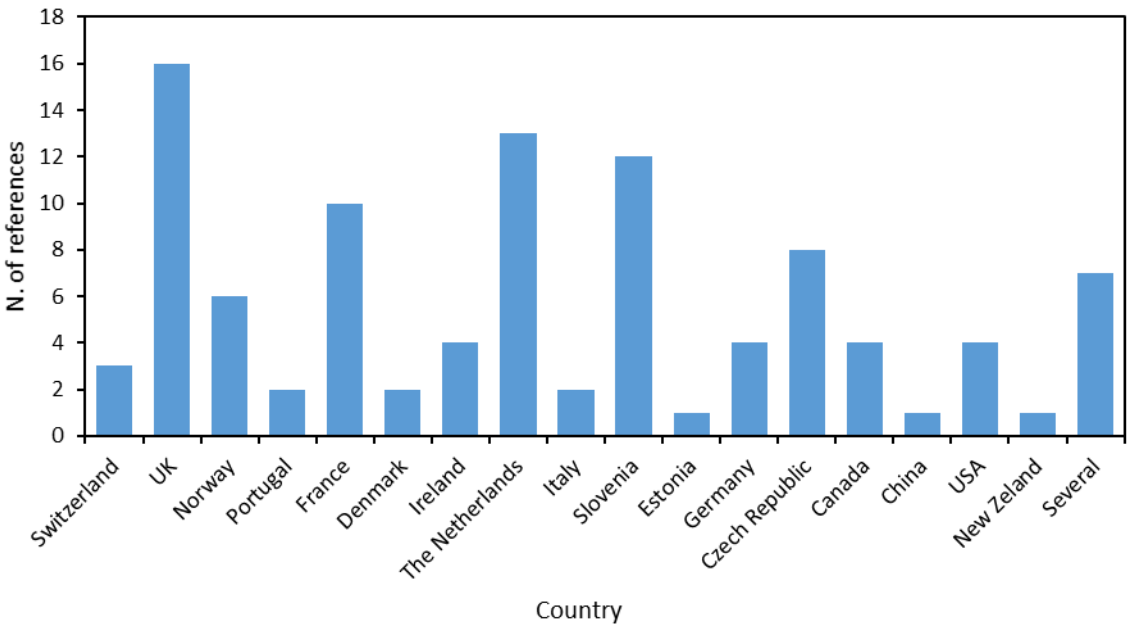

Figure 5. Frequency of the references regarding the country where the monitoring took place.

More than 80% of the studies refer to European countries.

Figure 6 presents the analysis of the references regarding to their subject and availability of monitoring data.

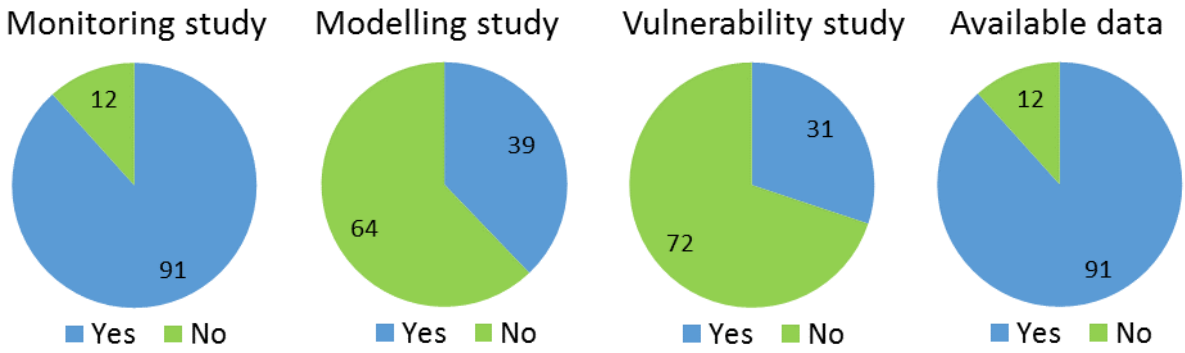

Figure 6. Analysis of the references regarding the subject and availability of monitoring data.

More than 90% of the references refer to monitoring studies. In these studies, monitoring data is available.

Despite 40% of the references including some kind of modelling, many of these publications only present simple mathematical correlations' based on the monitoring data collected from 2 or 3 sites.

4 | Assessment of the selected relevant references

4.1 Standard assessment of the references

Following the procedure presented in Figure 1, several sources of information were used to identify the most important literature references in the context of both road runoff monitoring and modelling. This work was endorsed to all consortium partners in order to have a global overview of the road runoff characteristics across Europe.

The matrix with analysis of the 103 literature references is presented in Appendix 1. As referred in section 2, the references were classified according to their relevance to the project, graded from 1 (poorly relevant) to 5 (highly relevant). The distribution of the references by this classification is presented in Figure 7.

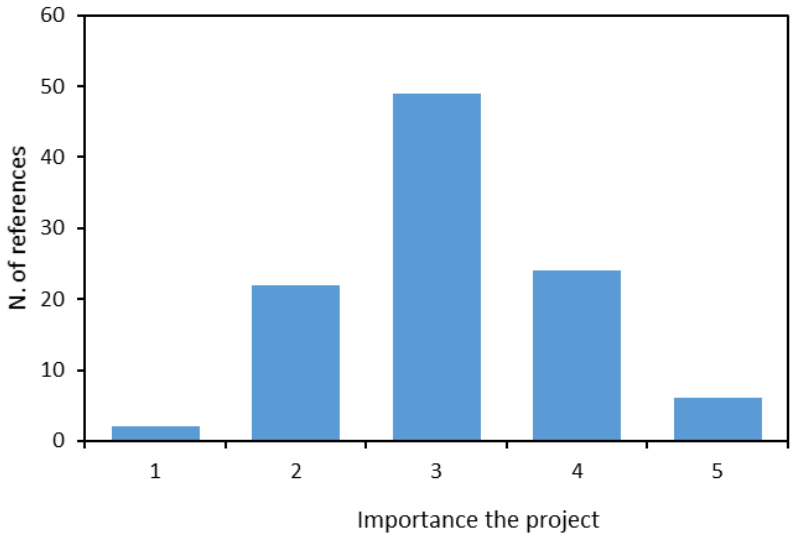

Figure 7. Analysis of the references regarding the importance for the project.

Six references were classified as highly relevant to the project, namely:

- Legret M. (2001) Pollution et impact d'eaux de ruissellement de chaussées. Technical Report LCPC Routes CR 27, 109 pp.
- Piguet P. (2007) Road runoff over the shoulder diffuse infiltration real-scale experimentation and optimization, PhD Thesis, EPFL, Lausanne, Switzerland
- Crabtree B., Moy F., Whitehead M., Roe A. (2006) Monitoring pollutants in highway runoff, Water and Environment Journal, 20, 287-294
- Kayhanian M., Suverkropp C., Ruby A., Tsay K. (2007) Characterization and prediction of highway runoff constituent event mean concentration, Journal of Environmental Management, 85(2), 279-295

- Kayhanian M., Fruchtman B., Gulliver J., Montanaro C., Ranieri E., Wuertz S. (2012) Review of highway runoff characteristics: Comparative analysis and universal implications. Water Research, 46, 6609-6624
- Huber M., Helmreich B. (2016) Stormwater Management: Calculation of Traffic Area Runoff Loads and Traffic Related Emissions, Water 2016, 8(7), 294

As the analysis of the references was made by all partners, some differences were observed in the procedure adopted to fill the matrix. Therefore, an effort was made to *standardize* the matrix content and provide basis for a more consistent evaluation of results.

4.2 Key pollutants

The composition and concentration pollutants that can be found in road runoff are affected by several factors such as for instance the rainfall pattern, road and vehicles configurations, ambient conditions and environmental attributes (*e.g*. Huber et al. 2016). These factors are assumed to have simultaneous and sometimes contradicting influences on the extent of pollutant presence in road runoff. The cause and effect relationships with regard to pollutants are complicated and often inconclusive. Even among obvious influencing factors such as daily traffic, there are contradicting findings from different studies. These arise because of significant variance in pollutant concentrations among study sites and within each site, between different runoff events, or to additional effects which have not been considered. It may be pointed out the change in the carburant properties over time.

According to Kayhanian *et al.* (2012) road runoff components may be divided in:

- **conventional water quality parameter:** total suspended solids (TSS), total dissolved solids (TDS), dissolved organic carbon (DOC), total organic carbon (TOC), chemical oxygen demand (COD), biochemical oxygen demand (BOD), oil and grease (O&G), hardness as $CaCO_3$, temperature and pH.
- **Metal constituents:** most frequently cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) and less frequently aluminium (Al), the metalloid arsenic (As) and iron (Fe).
- **Nutrient constituents:** nitrates (NO_3^-), nitrites (NO_2^-), ammonium (NH_4^+), total Kjeldal nitrogen (TKN), total nitrogen (TN), phosphate (PO_4^{3-}) and total phosphorus (TP). The authors conclude that the contribution of N and P from traffic-related sources in runoff appears to be less significant than that from surrounding land uses, such as agriculture.
- **Other less frequently measured water quality parameters:** faecal indicator bacteria (FIB), toxicity, polycyclic aromatic hydrocarbons (PAHs), herbicides and pesticides.

A list of sources of organic pollutants in road runoff may be found in Markiewicz *et al.* (2017). The authors identified the following sources: tyre wear, brake lining, integrated vehicle components, car care products, fuels, oils and lubricants, road construction materials, concrete or road paint. The organic pollutants emitted from each source and a selected number of priority pollutants were also identified.

The main sources of emitted PAHs were vehicle exhaust gases, followed by tyre wear, motor lubricant oils, road surface wear, and brake linings.

In order to improve the understanding of pollutants in highway runoff, a 5-year research study was conducted in the early 2000's in the UK. The monitoring work done in the scope of this study was presented for instance in Crabtree *et al*. (2006). It covered 6 highways with 10 events at each site and 40 constituents. The authors identified the following key constituents:

- Heavy metals: Cu, Zn, Pb;
- Herbicides: Glyphosate;
- Polycyclic Aromatic Hydrocarbons: Benzo(a)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Indeno(123)cdpyrene, Benzo(ghi)perylene;
- Deicing salts: Chloride;
- BOD;
- TSS.

The amount of available data limits the identification of relationships between event and site characteristics and the runoff quality at individual sites. Although pollutant concentrations in highway runoff are generally low, most constituents, and in particular metals, show higher concentrations following winter salt applications. The authors concluded that a relationship between runoff concentration and rainfall intensity is likely to exist.

Summing up, in the studies presented in the reference matrix (see Appendix 1), the most common constituents that were monitored in road runoff are TSS and the heavy metals (such as Cd, Cr, Cu, Ni, Pb, and Zn). PAH were mostly found in areas with colder climate conditions. Studies in Southern Europe showed PAH concentrations commonly below the detection limits and with maximum concentrations of 0,08 µg/L (example for Portugal presented in Barbosa *et al.* 2011). PAH persistence in the road pavement has been associated to colder climates with low solar irradiation and temperature.

4.3 Assessment of the most relevant publications including monitoring data

In the technical report, **Legret (2001)** presented the results of the monitoring field work in 3 highways located in France, namely:

(i) A11 highway in the Nantes metropolitan area, at the crossing of the Erdre river. This section of the highway comprises three lanes in each direction edged by crash barriers. At the time of the study, mean daily traffic was approximately 12000 vehicles per day in each direction (7% of trucks). Two monitoring field works were conducted.

(ii) RN12 four-lane motorway, approximately 50 km west of Paris. The mean daily traffic was 21000 vehicles/day (10% trucks). One experimental field work covering both sides of the motorway (one impervious and other porous) was conducted.

(iii) A1 highway, Wancourt rest area, near Arras (France). One experimental field work was conducted.

The field work carried out on at the A11 highway showed that the total hydrocarbons content of runoff water was quite high (between 0.14 and 4.2 mg/L, mean 1.2 mg/L).

Regarding PAH, only fluoranthene and benzo[ghi]perylene were above the detection limit and always with rather low concentrations (< 100 ng/L).

During the monitored events, pH remained close to 7. The most important concentrations of trace metals were for Zn and Pb, whereas Cu and Cd contents were generally low.

The use of salt as de-icing agent during winter was found to have great influence in the concentrations of TSS, Pb, Cd and Zn. EC was also strongly dependent on the season. Mean values of 190 µS/cm in summer and 3170 µS/cm in winter were observed, clearly showing the presence of de-icing salts during the winter season. In what regards the TSS, its mean content was 71 mg/L, with higher concentrations during winter and similar observations were made with respect to chloride and sulfate mean concentrations (respectively equal to 1012 mg/L and 93 mg/L during the winter period).

The two field works on the A11 highway were made before and after a replacement of the road impervious pavement by a porous asphalt layer, so different removal rates regarding both pavement types could be computed. Comparing the monitoring data, removal rates of 90% for the total HC, 94% for TSS and between 21% (Cu) and 74% (Pb) for trace metals were obtained. The field work on the RN12 motorway also showed a significant reduction of total HC, TSS, Cu and Cd than can be attributed to the porous asphalt. However, Pb and Zn do not seem to be retained by the pavement of the RN12 motorway, which is different to the monitoring results from A11 highway.

Moreover, the author observed that metals are mostly found under particulate form, except for zinc. Seasonal effects have great impact on the contaminants content.

Piguet (2007) conducted an extended monitoring field work in a two-way road located in the canton of Vaud (Switzerland), between the municipalities of Champagnes and Grandson. The monitored section of the road is 95 m long. Traffic was measured from January 2004 to the end of September 2005. The road is mainly used one way: 280 vehicles/day on the western lane and 1800 on the eastern lane. Peak traffic charge reached 5800 vehicles one day in June 2004.

A new method of road runoff management was developed and tested in a real-scale experiment undertaken in Switzerland. This concept is based on the infiltration of road runoff in the infiltration slope edging the road shoulder. Turbidity, TOC, EC and temperature were continuously monitored. The author analysed the road runoff quality taking into account the following six “families” of contaminants:

(i) Mineral trace elements (MTE)

The author uses the term MTE to identify metals and non-metallic elements usually addressed as “heavy metal”. MTE considered in the frame of this study are Zn and Cu. Despite the fact that this MTE may have anthropogenic and natural origin, the study considers only MTE originated in the road activities.

(ii) Polycyclic aromatic hydrocarbon (PAH)

PAH may come from natural sources but are above all the result of the combustion of organic materials and derivatives (carburant, wood, etc.). They chemically rather inert and need special condition for their degradation. This may augment their persistence in the environment. They easily accumulate in the biomass. Once in the environment, they easily sorb to solid matter. They might then be (bio-) degraded. The highest concentration of PAH is thus found in sediments. Overall, all PAH are highly toxic, representing a high risk for the environment.

(iii) Aliphatic hydrocarbons (C_x)

As for PAH, C_x may come from the natural environment; but their main source is the incomplete combustion of various oils, fuels and lubricants. They are emitted in the form of gases, volatile liquids and viscous solids. Aliphatic hydrocarbons are present in gases, gasoline, kerosene, lubricating oil and, for heavier compounds, in asphalts. All have a very low solubility in water. Those compounds are very stable and chemically inert. Overall, all C_x present a risk for human health.

(iv) Benzene – Toluene – Ethylbenzene – Xylenes (BTEX)

BTEX constitutes a significant part of the hydrocarbons used in fuels and lubricants. BTEX are highly volatile and are somewhat soluble in water. They have thus the tendency to stay in the solute phase and be transported farther than PAH. If trapped in water, they may be carried to the alluvial aquifer. This is generally not the case because they evaporate first.

(v) Gasoline additives

MTBE (Methyl Tertiary Butyl Ether) is easily produced by combining methanol and isobutene. It is used as a retardant and catalyser in hydrocarbons. It is liquid, volatile and flammable. MTBE is easily transported from the runoff to the aquifer. It is highly persistent.

(vi) Polychlorinated biphenyls (PCB)

PCB is a group of 209 compounds containing chlorine. They are made of a biphenyl core where hydrogen atoms are replaced by chlorine atoms. PCB are mainly found in hydraulic apparatus and electrical devices. They are used as lubricants and found in gearbox, motor oils and as plasticizers. They are now forbidden in most countries but they are nevertheless still found in the environment.

In the scope of the study of Piguet (2007), a total of 112 natural rainfall events were recorded (in November 2004 and April and September 2005). It was found that the first flush effect produces a peak of EC and MTE concentrations. Moreover, mobile MTE are always transported, whatever the rainfall intensity, whereas elements with low mobility are preferentially transported during high flow periods.

MTE are mostly transported in association with particles. The PAH with the highest molecular weights have the highest concentrations.

Among the specificities of this study, one can mention that the monitored road segment was new and the initial pollution was thus negligible. Two lysimeters allowed to perform *in situ* infiltration experiments and to calculate water and contaminants mass balances. Moreover, the underlying aquifer has been monitored, which may be important for the WP2 of the Project PROPER.

The concentrations of mobile MTE and PAH were correlated with EC whereas less mobile contaminants were more correlated with turbidity.

This thesis demonstrates that the presence of an infiltration slope improves the quality of the water: all contaminant concentrations are greatly reduced, and some pollutants even become undetectable. The environmental advantages of this new concept of roads are very clear.

Crabtree *et al.* (2006) monitored 40 constituents including 12 metals (totals and dissolved Cu and Zn), 16 PAHs, 5 herbicides, BOD, COD, hardness, Chloride, TSS and ammonia in 6 sites namely 2 way non-urban roads. Full details about the site such as drainage area or percentage running traffic area are provided. Flow-weighted highway runoff samples were collected for 10 wet weather events at each site. The study describes a 5-year study, which took place between 1997 and 2002, where data were collected to improve the understanding of pollutants in highway runoff and the treatment efficiency of the drainage systems.

The monitoring data were used to identify ranges of pollutants concentrations in highway runoff, relationships between runoff concentrations/loads and both highway and climate variables, drainage system treatment efficiencies, and impacts on receiving waters.

The authors present the event mean concentrations and loads for a total of 60 events (10 events at 6 sites). Concentrations for the key pollutants (as referred by the authors) are presented in the Table 1.

Table 1. Summary of event mean concentrations in road runoff from all sites (adapted from Crabtree *et al.* 2006)

Constituent	EMC
Copper	41 µg/L
Copper (dissolved)	20,58 µg/L
Zinc	140,3 µg/L
Zinc (dissolved)	57,49 µg/L
Lead	23,05 µg/L
Glyphosate	0,72 µg/L
Benzo(b)fluoranthene	0,14 µg/L
Benzo(k)fluoranthene	0,09 µg/L
Benzo(a)pyrene	0,15 µg/L
Indeno(123)cdpyrene	0,11 µg/L
Benzo(ghi)perylene	0,08 µg/L
Chloride (de-icing salt)	258,43 mg/L
BOD	6,59 mg/L
TSS	114,58 mg/L

The amount of available data limited the identification of relationships between event and site characteristics and the runoff quality at individual sites. A relationship may exist between runoff concentration and rainfall intensity.

The authors found a relationship between the climate season and the road runoff quality. Although pollutant concentrations in highway runoff are generally low, most constituents, and in particular metals, appear to be elevated following winter salting. Figure 8 illustrates this pattern in the data for a particular site.

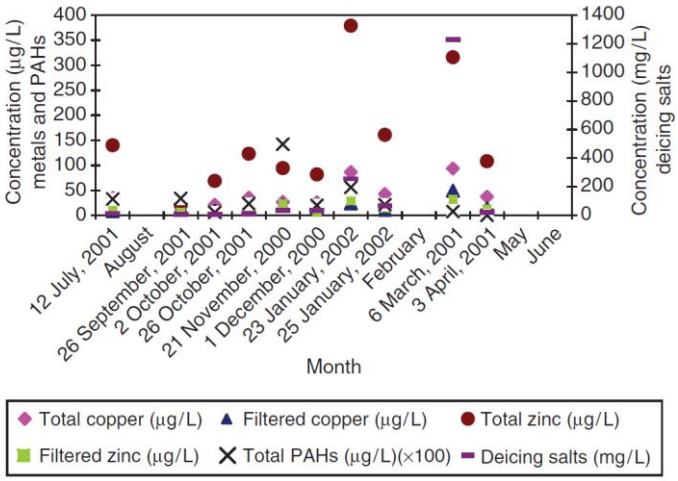

Figure 8. Seasonal pattern in road runoff data from A34 Gallos Brook in the UK (adapted from Crabtree *et al.* 2008).

Kayhanian *et al.* (2007) analysed the monitoring data from 34 highway sites in California during 2000-2003. The authors collected samples for an average of 8 events per site. The analysed runoff constituents were pH, electrical conductivity, hardness, TSS, TDS, OC, DOC, total and dissolved metals (As, Cd, Cr, Cu, Ni, Pb and Zn) and nutrients: nitrate, TKN, total P and ortho-P.

Regarding the climate conditions, it should be pointed out that California is placed at a similar latitude as Southern Europe with a similar climate pattern, this being the reason for including this study in the present report. In the monitored sites, average annual rainfall ranges between 152 and 1016 mm.

The authors obtained constituent event mean concentrations generally higher in urban highways than in non-urban highways. The chemical characteristics of highway runoff in California were compared with national highway runoff chemical characterization data and multiple linear regression (MLR) analyses were performed to evaluate the impact of various site and storm event variables on highway runoff constituent EMCs. The parameters that were found to have relevant impacts on road runoff characteristics (i.e. EMCs) include: total event rainfall; cumulative seasonal rainfall; antecedent dry period; contributing drainage area and annual average daily traffic. Surrounding land use and geographic regions also showed to have a significant impact on runoff quality. The MLR model was also used to predict constituent EMCs. Further details on the multiple linear regression model developed in Kayhanian *et al.* (2007) will be presented in section 4.5.

Following the previous study, **Kayhanian *et al.* (2012)** summarize and compare different highway runoff characterization studies performed in Europe, North America, East Asia and Australia / New Zealand.

Historical trends, first flush effects, pollutant form (dissolved vs. particulate) and surrogate water quality parameters are discussed.

The references used to perform the analysis in Kayhanian *et al.* (2012) included the characterization of the site (*e.g*. number of highway lanes, pavement type, fraction of impervious area, annual average daily traffic, drainage area and land use) and climate characteristics. Aggregate water quality parameters, metals, nutrients and PAHs were summarized. The most commonly measured aggregate parameters are TSS and chemical oxygen demand. The concentrations of Cd, Cr, Cu, Pb, Ni and Zn have been reported in the majority of the studies, whereas the most frequent analysis done on nutrients were TKN or total N and total P. PAHs, herbicides and pesticides have been less studied.

This meta-study demonstrates a massive reduction of Pb concentration in highway runoff linked to the leaded gasoline regulation. However, there is no clear decrease nor increase of other metal contaminants. According to the results in the several analysed references, the existence of a first flush effect has been universally recognized. The partitioning of pollutants shows that higher metal concentrations are generally associated with smaller particles. Pb, Al, Fe, As, Cd and Cr are mostly in particulate form, whereas Zn, Cu and Ni are mostly found in dissolved form. Finally, there is a strong correlation between TSS, TDS, total organic carbon, Fe and 13 other constituents and water quality parameters (turbidity, oil and grease, total HC, dissolved organic carbon, TKN, EC, chloride, Cd, Cr, Cu, Ni, Pb, Zn).

The median concentration of most pollutants was generally 20-30% higher in Europe than in North America. Most metal pollutants and phosphorus are associated with particles (with some inconsistencies for Cu, Zn, Ni and P which are shown to be mostly in dissolved form in some studies).

Huber and Helmreich (2016) refer to a monitoring study where the focus constituents were the heavy metals. The authors conducted a state-of-the-art study and collected data from a literature survey from case studies in Brazil, Switzerland, Germany, France, Great Britain and USA from similar time frames.

Due to their occurrence, toxicity and non-degradability, the authors point out antimony, cadmium, chromium, copper, lead, nickel, and zinc as the highly relevant heavy metal pollutants in road runoff. Long-term measurements of their concentrations, the corresponding water volumes, the catchment areas, and the traffic volumes can be used to calculate specific emission loads and annual runoff loads that are necessary for mass balances. The annual runoff loads for a specific catchment area (e.g., g/ha) were summarized and discussed in this paper for all seven metals and three types of traffic areas (highways, parking lots, and roads; 45 sites). In Figure 9 the annual total heavy metal loads in highways, roads and parking lots are presented.

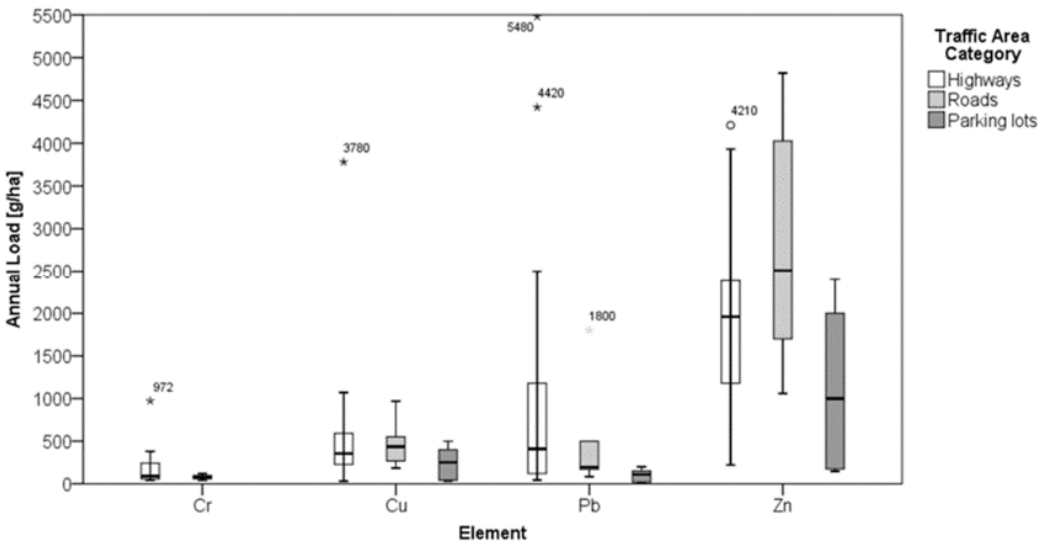

Figure 9. Annual total heavy metal loads of Cr, Cu, Pb, and Zn in runoff from traffic areas for each of the three categories highways (H), roads (R), and parking lots (P) (adapted from Huber and Helmreich 2016).

For example, the calculated median annual runoff loads of all sites are 355 g/ha for copper, 110 g/ha for lead (data for the 21st century), and 1960 g/ha for zinc. In addition, historical trends, annual variations, and site-specific factors were evaluated for runoff loads.

For Germany, mass balances of traffic related emissions and annual heavy metal runoff loads from highways and total traffic areas were calculated. The influences on the mass fluxes of the heavy metal emissions and the runoff pollution were discussed. However, a statistical analysis of the annual traffic related metal fluxes (in particular for different traffic area categories and land uses), was not possible because of a lack of monitoring data.

The traffic related emissions in Germany were estimated for seven different sources (tyre wear, brake lining wear, roadway abrasion, weights for tyre balance, street furniture, and de-icing salts). Zn is mostly emitted by galvanized elements and tyres, Cu and Pb by brakes, and Cd by de-icing salts. The calculated loads are comparable with the ones presented in other studies in Europe for most metals. However, a statistical analysis of traffic related metal mass fluxes was not possible because of a lack of monitoring data. The estimation of the runoff loads and the emission loads for Germany specified that the vehicles, the road design, and the winter services emit heavy metals in large quantities and the runoff also contains high amounts of metal loads per year. The most relevant metals are Cu and Zn because the annual Pb loads have decreased significantly in the last few decades and traffic related Cd and Ni contribute only 5% and 11% of the total emissions in Germany, respectively.

4.4 Tentative characterization of patterns for road runoff pollutants

After the analysis of the comments made to all literature references in the matrix presented in Appendix 1 and the assessment of the most relevant publications regarding monitoring, in this section, a tentative characterization of patterns of road runoff pollution is provided.

In the literature references several issues regarding road runoff quality were studied. In this analysis, the following key topics will be considered: (i) first flush effect (*i.e.* higher pollutant concentrations at the beginning of an event); (ii) type of pollutants; (iii) what does affect the pollutant concentration/loads; (iv) influence of the type of pavement.

As referred above, the occurrence of a first flush in road runoff is generally recognized. Barrett *et al.* (1995) highlighted that this effect was rather evident but was generally limited to a small volume. The authors considered that the overall effect was small or negligible. Piguet (2007) linked the percentage of the transported mass in the first 30% of the road runoff volume to the intensity of the precipitation and the antecedent dry period. Its occurrence is also dependent on the shape, size and slope of the catchment area.

The first-flush effect was found to have a significant influence on the removal of metals in the road runoff waters (Hewitt and Rashed 1992). The behaviour of the particle-associated material and total PAHs closely follow that of the TSS. A simple regression model based on the length of the antecedent dry period (ADP) and the rate of discharge was used to make accurate predictions of the rate of removal of Pb. The same good correlation between removal rate and length of the ADP was not found for the other pollutants. Although the obtained regression parameters are site specific, the methodology described and the type of mathematical relationships established between pollutant load, discharge rate and ADP should be applicable elsewhere and for different pollutants.

The comparison of the numerous studies presented by Legret (2001) shows that the type of pavement (impervious or porous) affects the quality of highway runoff waters. The removal rate associated with a porous pavement can be quite important. This author, for instance, obtained between 20 and 75% for metals, more than 85% for TSS and approximately 90% for heavy metals. These removal rates are mostly due to the retention of the fine particles by the porous pavement.

The monitoring results depended greatly on the rainfall event, characteristics of the pollutants and the units used to express the concentrations (*e.g.* molar concentration, mass concentration, flux or dissolved/particulate proportions). Due to the complex mechanisms that took place in pollutants emissions, accumulation on the road environment, physical, chemical and biological processes that took place during the antecedent dry period and the wash-off process, this variability could not be statistically explained by just data regarding rainfall, such as the precipitation depth, the rainfall intensity or the duration of the antecedent dry period.

For **The Netherlands**, van Duijnhoven *et al.*(2013) refer that the differences found among the various roads are large and it was therefore not possible to draw a conclusion for the entire country. Concentrations in runoff from regular asphalt highways and secondary roads are larger than concentrations in runoff from porous asphalt highways and secondary roads. In the same country, Tromp (2005) and van den Berg (2009) found that the concentrations of PAHs, Cu and Zn in road runoff are higher than the national water quality standards.

For **China**, Gan *et al.* (2007) state that highway runoff is nearly neutral with low biodegradability and O&G, TSS and heavy metals are the dominant pollutants. Comparing to rural sites, EMCs of constituents

at the urban road are 6-73% higher except for pH, TOC and OP. Rainfall depth and ADP can explain approximately 30-70% of the variation in the EMCs except for TOC, SS, TP and Cr. Moreover, the surface soil layers adjacent to the discharge from the rural site have been contaminated by heavy metals (down to 40 cm depth).

Based on several monitoring studies in **Portugal** during the years 1996 to 2010, Barbosa *et al*. (2011) found, based on more than 100 events regarding 10 national roads[1], that concentrations of TSS and Fe exceeded the limit for wastewater disposal in the environment.

For **Norway**, Ranneklev (2016) showed that levels of metals and organic contaminants were high and exceeding the environmental quality standards in the EU Water Framework Directive. High concentrations of Cu, Zn, Pb, PAH, and suspended solids were frequently reported. In addition, high concentrations of road salt were found during snow smelt. Negative effects on the aquatic environment due to effects from road salt in contaminated snow were most pronounced according to the literature reviewed.

Higgins (2007) and the related references Higgins *et al.* (2008), Desta *et al.* (2007) and Bruen *et al*. (2006) studied road runoff pollution in **Ireland**. They reported the monitoring data of approximately 200 individual storm events over a 15-month period at 4 non-motorway sites in **Ireland** and demonstrated clear relationships between storm event characteristics and pollutant concentrations and loadings. Rainfall intensity/volume and ADP appear to be the principal driving variables, together with traffic volume and preceding conditions only showing weak correlation. During the monitoring period, samples were collected in 4 different sites. The characteristics of the constituents measured were broadly comparable to those observed from similar conditions in other European countries. The authors pointed out that the heavy metals concentrations in the order of Cd<Pb<Cu<Zn with heavy metals, TSS and phosphate PO_4^{3-} frequently exceeding EU EQS.

Based on state-of-the-art analysis, Kayhanian *et al.* (2012) quantified the decrease in road runoff heavy metals concentrations for **North America** (NA) and **Europe** (EU). Clearly, the current average Pb concentration is substantially lower compared to early historic data. However, Kayhanian *et al.* (2012) pointed out that a clear decrease was not observed for the other heavy metals.

[1] One of the results concern tunnel wash monitoring, therefore although providing information on pollutants cannot be used for comparison to road runoff under natural conditions.

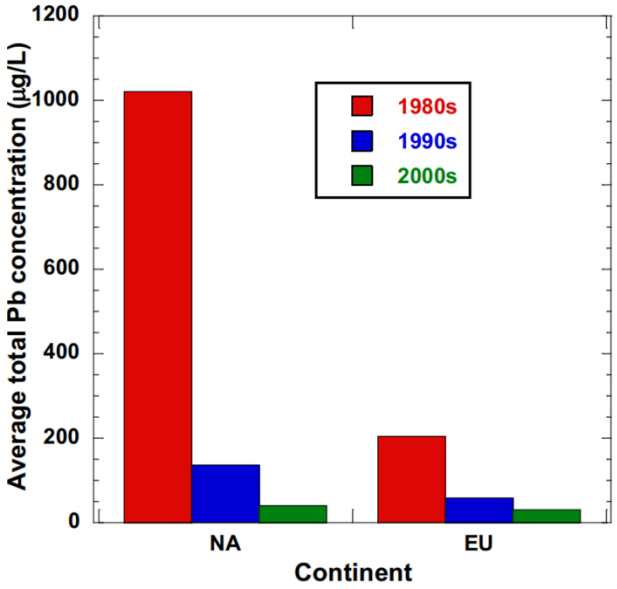

Figure 10. Trend of average total Pb concentration in highways runoff from 1980s to present (adapted from Kayhanian *et al*. 2012).

The sources of pollutants in road runoff are identified in several references. It is acknowledged that this identification is nowadays well established (*e.g.* Branchu *et al*. 2013).

As referred above, in Markiewicz *et al.* (2017) the organic pollutants emitted from vehicles and traffic-related activities are characterized and their sources are well identified (tyre wear, brake lining, integrated vehicle components, car care products, fuels, oils and lubricants, road construction materials, concrete or road paint).

Piguet (2007) presented a rather complete list of sources of road runoff pollutants (*cf.* Table 2).

Table 2. Sources of pollution in road runoff (adapted from Schlaepfer *et al.* 1996 *in* Piguet 2007).

Source	Substance
Carburant, gasoline	Lead, nickel, zinc, soot, PAH, C_x, BTEX
Oils, lubricants and greases	Lead, zinc, nickel, PAH, C_x, BTEX, PCB
Exhaust gas	Brome, lead, nickel, PAH, C_x, BTEX, MTBE
Exhaust gas catalyser	Platinum, palladium, rhodium, PAH, C_x, BTEX, MTBE
Brake pad	Copper, chromium, nickel, manganese, lead, dirt
Tyres wearing	Rubber, soot, Sulphur, zinc oxide with cadmium and lead traces
Wearing course	Particles and colloids: Zinc, silicate, calcium, magnesium PAH
Concrete	Dirt
Asphalt	Dirt, PAH
Tar	Organic compounds, PAH
Marking paints	Rutile
Railing, signalization	Iron, zinc, chromium, nickel
Corrosion, wearing	Aluminium, copper, iron, cobalt, manganese
Maintenance services	Sodium, calcium, chlorine, sulphaye, herbicides, etc.

In the table, C_x, BTEX, PCB and MTBE refer to Aliphatic hydrocarbons, Benzene – Toluene – Ethylbenzene – Xylenes, Polychlorinated biphenyls and gasoline additives, respectively. Details on these substances are presented in section 4.3.

Monitoring data from several roads in **Portugal** (gathered for instance in Barbosa *et al.* 2011) allowed the definition of a pattern for the road runoff pollution in Portugal. The event mean concentrations for 9 roads in Portugal are presented in Table 3.

Table 3. Event mean concentrations for several roads in Portugal (adapted from Barbosa *et al.* 2011).

	A1 (2002)	A1 (2009)	A2 (2003)	A6 (2004)	A25 (2003-04)	A25 (2008)	A3 St Tirso (2009)	A3 Pt Lima (2010)	A22 (2009)	IP4 (1996-98)	IP6 (2005)
AADT (vehicles/day)	30299	27746	16344	2918	27000	14675	42823	7849	19201	6000	6539
TSS (mg/L)	84,5	22,2	7,4	19,6	44,7	67,7	6,8	16,9	52,4	8,1	224,7
Chlorides (mg/L)	-	6,7	-	-	-	108,2	7,7	6,7	23,3	-	36,5
COD (mg/L)	-	81,9	-	-	83,0	109,1	22,2	70,2	38,3	-	195,9
Fe (mg/L)	0,724	0,350	0,333	0,353	1,482	2,746	0,105	0,224	1,9	-	-
Zn (mg/L)	0,159	0,127	0,208	0,346	0,205	0,134	0,214	0,177	0,16	0,308	0,076
Cu (mg/L)	0,034	0,020	0,033	0,008	0,014	0,072	0,027	0,009	0,03	0,024	0,032
Pb (mg/L)	0,012	0,003	0,004	0,002	0,005	0,044	0,006	-	0,02	0,012	0,009

Regarding heavy metals, the authors identified the following pattern in terms of concentration Zn >> Cu > Pb and lower concentrations of Cd and Cr. A rather high reduction of the concentration of Pb is observed in most recent studies in **Portugal**, compared to early studies (1996).

For Portugal, a few measurements of PAH and O&G revealed values below the quantification limit. The effect of the temperature and the high solar radiation, enhancing the volatilization and degradation of the pollutants are likely to explain these observations. This is in line with Crabtree *et al.* (2008) that identified the presence of PAH only in the colder regions of **England**.

From chemical analysis of road runoff in **Canada**, Mayer *et al*. (2011) highlighted that PAHs, metals and road salts constitute major classes of contaminants in highway runoff. Vehicular traffic and highway structures (*e.g*. galvanized bridge drains) can be important contributors of metals to runoff. Furthermore, road conditions (age and composition of pavement) can be important contributors of PAHs. Finally, road salt constituents are contributed by applications of chemical de-icers during winter road maintenance. These constituents (chloride) not only have an adverse effect on the salinity of runoff, but they are also a contributing factor to the increased concentrations of dissolved heavy metals, their mobilization and bioavailability.

According to Barrett *et al.* (1995), the road runoff pollutant concentrations appear to be affected by changes in traffic volume, rainfall intensity, and other factors. In addition, vehicles provided a continuous input of pollutants to the road surface and runoff for the duration of runoff events.

Moy and Crabtree (2003) analysed a long term monitoring dataset. It included full rainfall records at 1 minute intervals, for 10 storm events over 13 months. Sediment sampling showed elevated HMs and

PAHs associated with the road runoff. Many of the individual PAHs species exceeded EU EQS. No statistical trends or relationships found between rainfall characteristics (or ADP) and pollutant concentrations or loads although an apparent relationship existed for low rainfall intensities and high flows during summer months.

As referred in Opher and Friedler (2010), the sources for the pollution in road runoff may be clear and constant (such as the type of pavement) or nearly impossible to measure or estimate. The aspects related to rainfall pattern, road characteristics, ambient conditions and environmental attributes are assumed to have simultaneous and sometimes contradicting influences on the extent of pollutant presence in highway runoff. Hence the cause and effect relationships with regard to pollutants in highway runoff are complicated and often inconclusive. Even among obvious influencing factors such as daily traffic, there are contradicting findings from different studies.

For example, SETRA (2007) presents a simple method to calculate road runoff loads (kg/ha) for SS, COD, Zn, Cu, Cd, Total Hydrocarbons and HAP in **France**. It classifies annual road traffic volume in below and above 10 000 and present equations based on monitoring studies from SETRA, since 1992. The study also indicates how to calculate average annual concentrations in road runoff discharges. It uses a classification of “open” and “restricted” roads, differentiating the sections that are excavated (restricted) where more likely particles are dispersed. SETRA (2007) establishes as well an equation for calculation of average annual concentrations of the pollutants in road runoff. This calculation is based on the annual load (kg), impervious surface (ha), average annual precipitation (m) and a factor/rate of reduction of works.

Taking into account the importance that the climate conditions have in the road runoff pollution characteristics, Figure 11 presents an overview of the average annual temperature and total precipitation for Europe.

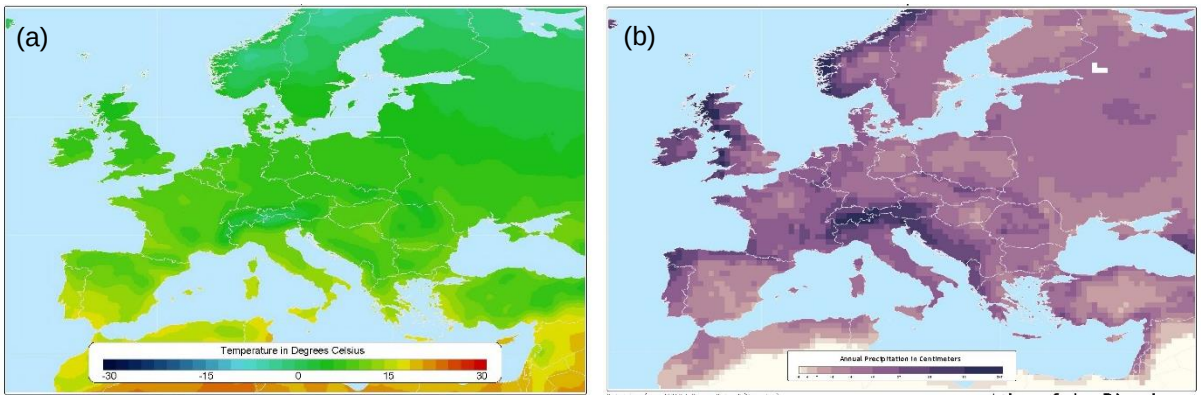

Figure 11. (a) Average annual temperature and (b) Average annual total precipitation (adapted from Atlas of the Biosphere, Centre for sustainability and the Global Environment; University of Wisconsin).

These maps point out the differences in the climate conditions across Europe and the distinction between the warm and dry Mediterranean climate in the South and the cold and humid climate in the North. As referred above, together with the radiation hours, the duration of the dry periods or the intensity

of the precipitation, these variables play a role and are relevant for understanding and predicting road runoff characteristics.

4.5 Summary of the most relevant references addressing modelling tools

As observed above, the road runoff characteristics are highly variable and depend on several conditions. Inconsistent conclusions have been obtained regarding how specific variables affect highway runoff (*e.g.* Huber *et al.* 2016). Therefore, the prediction of pollutant concentrations is a challenging issue. The prediction models are mainly based on regressions obtained from a selected number of monitoring field works and their application in a broader context should be carefully made.

A summary of the considered models is presented in Table 4. These models will be further described and analysed in task 1.2. At this stage, it is considered that the set of possibilities regarding modelling tools are already diverse and interesting to future developments. Taking into account Figure 11, it seems as well that this collection of prediction tools represent Northern and Southern Europe climates.

D1.2 will present and summarize the survey of tools, including the pros and cons regarding its use in the different European contexts.

Table 4. Summary of the models considered in the present analysis.

Reference	Pollutants	Name	Method	Input variables	Comments
Higgins *et al.* (2007)	TSS	-	multiple linear regression	Duration of the storm, discharge volume, rainfall intensity, antecedent dry period and number of vehicles travelled in the ADP	Developed for Ireland
Kayhanian *et al.* (2007)	TSS, TDS, DOC, TOC, Cu, Pb, Ni, Zn and nutrients P, TKN and No3-NCu and Ni	-	multiple linear regression	total event rainfall (TER); cumulative seasonal rainfall (CSR); antecedent dry period (ADP); contributing drainage area (DA); and annual average daily traffic (AADT)	Established for California, USA
Barbosa *et al.* (2011)	TSS, Zn, Cu, Pb	PREQUALE	Multiparametric equation	A – drainage area in km^2 I – Impervious percentage area (%) P – Mean precipitation height for a rainfall event with duration equal to the concentration time of the catchment (mm) P_{anual} – Annual mean precipitation	Established for Portugal
Crabtree (2008)	**Soluble pollutants associated with acute pollution impacts:** Expressed as mean event concentration (ug/L) for dissolved copper and zinc **Sediment related pollutants associated with chronic pollution impacts:** Expressed as event mean sediment concentration (mg/kg) for total copper, zinc, cadmium and (ug/kg) for pyrene, fluoranthene, anthracene, phenantrene and total PAH.	HAWRAT (Highways Agency Water Risk Assessment Tool)	Spreadsheet	**Event variables (input):** - Month; - Event total rain; - Rainfall duration; - Maximum hourly intensity; - Antecedent dry period; - Unit river flow **Event variable (calculated):** - Loss deducted event total rainfall; - EMC (Cu, Zn); - EMSC (Cu, Zn, - Cd, PAH); - Runoff volume (impermeable); - Runoff rate (Impermeable, permeable, total); - Discharge duration to watercourse without attenuation; - Discharge duration to watercourse with attenuation; - Total runoff volume and River Flow; - Dissolved Cu/Zn river concentration; - Attenuated discharge; - Dissolved Cu/Zn after mitigation	Blackbox spreadsheet (without concentration calculation) Established for the UK
Granato (2013)	The model is preloaded with "total phosphorus and "Total Suspended Solids", however the user can add additional inputs which were previously preloaded in the Highway runoff database.	SELDM (Stochastic Empirical Loading & Dilution Model)	Software package	Input variables for SELDM are based on site characteristics and representative statistics for each hydrologic variable. Each of these variables may be characterized by different probability distributions.	Established for the USA
Gardiner *et al.* (2016)	The RSS model provides estimates of risk to waterbodies based on zinc and copper concentrations in stormwater runoff derived from modelled loads; other stormwater contaminants are not included although these metals provide a proxy for stormwater pollution.	RSS (road stormwater screening)	Spreadsheet	- Carriageways - AADT - Drainage - Surface water channels	The methodology was developed to address the longer-term risks to waterbodies from the total annual loads of zinc and copper in stormwater runoff. The risk assessment does not take account of variations in copper and zinc concentrations during storm events and the potential effects of these variations.

5 | Database matrix

The draft structure of the Database matrix was discussed at the 1st Project meeting (Cologne, Germany, the 17th October 2017). After the meeting, a deadline was set for everyone to send comments. After having integrated the received contributions from all, a final database matrix has been established and is briefly presented herein. This is the named Matrix 2, one of the outcomes from task 1.1, and all PROPER partners will be responsible to provide suitable data.

The database matrix has 4 main fields of information, namely:

(i) Source of data;
(ii) Road characteristics;
(iii) Drainage basin;
(iv) Characterization of the events.

For the *Source of data*, besides the name of the partner responsible for the data and a dataset code, the partner must identify if the data were already published and where or if it is unpublished data.

Regarding the *Road characteristics*, partners should give details on the location of the runoff sampling collection (coordinates), the length and width of road, the annual average daily traffic (ADT, number of vehicles) and the type of pavement.

In the *Drainage basin field* details about the total and paved areas and average annual rainfall should be provided. In the selection of the case studies, it is decided that it is appropriated for the purposes of the project to take up monitoring results from catchments with a minimum of 85% of the total area being paved/road area.

The *Characterization of the events* is crucial for having consistent and needed data required to perform the following tasks 1.3 and 1.4. This characterization may change from dataset to dataset but should include at least data regarding the precipitation events (*e.g.* intensity), flow discharge, antecedent dry period and the concentration of the identified key pollutants in road runoff (TSS, and heavy metals: Zn, Cu, Pb, Cd, Cr and Ni). The units to express the pollutants concentrations are common (mg/L), allowing to compare and use the Data Matrix as a source of homogeneous data for tasks 1.3 and 1.4

6 | Conclusions

This report is the PROPER project deliverable 1.1 and concerns the results from task 1.1 *Literature review on road runoff pollution on Europe*. This task is completed with this output.

All partners contributed to the literature review and to a standard analysis of the references. A total of 103 literature references were listed, comprising 48 scientific papers, 31 technical reports, 9 conference proceedings and 15 other documents. As expected, the most common types of publication are scientific papers and reports. They represent about 78% of the total number of references.

Eight of the 103 references date from the 1990's, and 53 references are from year 2007 up to 2017, which means that the overall collection represents an updated review. The references are written in 10 different languages and English is, as expected, the most common language (about 70% of the listed references).

More than 90% of the references refer to monitoring studies. In these studies, monitoring data are also available. Although 40% of the references include some kind of modelling, most of the publications present only simple mathematical correlations' based on the monitoring data collected from 2 or 3 sites. Therefore, they refer to site specific correlations between pollutant concentrations and field and weather conditions and should be carefully used for other conditions.

The references were, as well, classified according to their relevance to the project, graded from 1 (poorly relevant) to 5 (highly relevant). The distribution of the references by this classification shows that only six references were classified as *Highly relevant* to the project. Almost 50% are considered *Relevant with monitoring data* (the intermediate grade).

The report presents the most relevant literature updated references on road runoff, and Appendix 1 includes the entire list and contents from the 103 selected literature references.

The six references graded as *Highly relevant* include monitoring data and respect to work done in **France** (Legret, 2001), **Switzerland** (Piguet, 2007), **United Kingdom** (Crabtree *et al*. 2006), **California** (**EUA**, Kayanian *et al.* 2007); a state-of the art analysing case studies from **Brazil**, **Switzerland**, **Germany**, **France**, **UK** and the **USA** (Huber and Helmreich, 2016) and a review of international highway runoff characterization studies (**Europe**, **USA**, J**apan**, **China** and **Australia**, by Kayhanian *et al.* 2012). These six references are valuable to have not just a European but rather an International overview of issues regarding road runoff characteristics. It is acknowledged variability in all quality parameters from each continent and among continents.

The occurrence of first flush effects of pollutants, and the fact that pollutants may be found as dissolved and particulate in road runoff are commonly recognized and addressed. Both effects seem to have distinct roles in the road runoff pollutant characteristics as first flush is generally limited to a small volume. Most metal pollutants and phosphorus are present in both the particulate and dissolved forms. Moreover, the removal rate associated with a porous pavement can be quite important.

Due to the complex mechanisms that take place in pollutant emissions, accumulation on the road environment, physical, chemical and biological processes taking place during the antecedent dry period and the wash-off process, this variability cannot be statistically explained by just data regarding rainfall, such as the precipitation height, the rainfall intensity or the duration of the antecedent dry period.

Kayhanian *et al.* (2012) states that first flush effects of pollutants based on concentration have been reported consistently. However, first flush effects for pollutants mass have been reported inconsistently compared with concentration first flush effect.

Regarding the evaluation of road runoff key pollutants, the most common constituents monitored accordingly to this literature review are TSS and heavy metals (such as Cd, Cr, Cu, Ni, Pb, and Zn). PAH were mostly found in relevant concentrations in areas with colder climate conditions. This information is relevant for Tasks 2.2, 2.4 and 2.5, also taking into consideration the European legislation (that is being analysed under Task 2.3).

Other relevant outputs from this task is the Database Matrix, presented in section 5 that includes all data to be provided and organised regarding the monitoring studies databases that are the subject of Task 1.3. The variables used for expressing the variables have been defined in order to obtain a final Matrix with homogeneous data.

It is understood that although road runoff monitoring practices are commonly addressed similarly, the variability that takes place over time, in the materials used (for both street furniture and vehicles), in road construction and design, maintenance practices and climatic factors, including the known climate change scenarios are producing continuous changes in road runoff pollution characteristics and therefore it is very important that monitoring studies continue to take place regularly, and in different countries/sites. It could be interesting to see more road runoff monitoring studies carried out in Central Europe. The more common the monitoring methodologies are, including the choice of key pollutants to be characterised, the more is the added value for a European overview and for possibly feeding European guidelines and policies.

This literature review highlighted the fact that the differences between the conditions (*e.g.* traffic, climate or pavement) are rather important in the road runoff characterization which makes it difficult to have common and final conclusions for the entire continent. The present analysis enabled however the identification of important patterns and trends that will be essential for the remaining tasks of WP1.

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APPENDIX 1 – List and contents of literature references

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[1]	Branchu P., Badin A.L., Bechet B., Eisenlohr L., Le Priol T., Marseille F., Trielli E. (2013) *Pollution d'origine routière et environnement de proximité, VertigO - la revue électronique en sciences de l'environnement* , Vertigo, Hors-série 15, Feb/2013	Paper	2013	FR	Yes, it summarizes the main results of studies conducted in France on chronic pollution in road environments from sources to receiving environment. Pollutants : trace metals, PAH, PGE	No	No	Mainly graphs. Data may be collected from cited references	No specific site. Review based on different peer-reviewed Papers and Reports.	Exhaust gas emissions, vehicle, pavement and equipment wears are sources of chronic pollution in road environment. Dry and wet atmospheric deposits and road runoff transfer pollutants from road network to its vicinity, potentially impacting superficial waters groundwater, atmosphere, soil and vegetation. The environmental balance of this pollution (sources, transfer, impact) has been documented since the eighties. On the basis of this knowledge, methodologies have been developed and help to implement public policies relative to road networks. In France, the scientific and technical network of the Ministry in charge of transports (present Ministry of Ecology, former Ministry of Equipment) has realised a large part of this work involving researchers, technicians and road network stakeholders. This article aims at illustrating researches and associated methodological developments performed from last 30 years.	Several studies were carried out over the last 30 years in France on the traffic-related chronic pollution focusing on the sources up to the environment contamination. Knowledge about pollutants and environmental transfer has therefore evolved, as well as the regulation. Some research questions should be deeper examined, such as transfers between the various environment compartments to understand the losses of pollutants from emission to receiving waters. Other questions and concerns have emerged, such as the quantification and transfer ways of PGE in waters and sediments. The main issue is the conformity of stormwaters to the WFD. When roadside zones have to be taken into account in urban planning, the potential contamination of water and soil is one of the challenges for future land-use.	2
[2]	Béchet B., B. Durin M. ,Legret P., Le Cloirec (2010) *Size fractionation of heavy metals in highway runoff waters*, Highway and Urban Environment, Alliance for global sustainability bookseries 17, S. Rauch et al.(eds.), Springer	Paper	2010	EN	Yes Both dissolved and particulate fractions (0.45 µm cut-off) have been analysed for major and trace elements. The distribution of metals among particulate, colloidal and dissolved fractions (8 µm and 5 kDa cut-offs) has been also studied. Pollutants : metals (Cd, Cr, Cu, Ni, Pb, Zn)	No	No	Yes.	The experimental site is located on the south bypass motorway of Nantes (Loire-Atlantique, France), where it crosses the Loire River at the Cheviré bridge. Opened in 1991, the Cheviré bridge supported in 2010 an average total daily traffic of 90,000 vehicles. The bridge is 1500 m long and 24.6 m wide. Carriageways consist of three lanes in each direction, separated by a central reservation and the pavement consists of a conventional asphalt surface. The runoff waters of the 19000 m^2 contribution area are collected in gulleys and flowed in aluminium collectors. Then, they are gathered in a detention-infiltration basin. Nantes has an oceanic climate with a mean annual rainfall of 820 mm over the last 50 years. Between August 2004 and May 2006, runoff waters were sampled in a concrete pipe, at the inlet of the basin, with an automatic sampler to take mean samples according to time during rain events. 21 samples were taken over the year (3 events in spring, 7 in summer, 9 in autumn and 2 in winter).	Several studies on runoff waters highlight the partitioning of trace metals in runoff waters between particulate and dissolved-bound fractions, the “dissolved” fraction being operationally defined by filtration through a 0.45-µm pore size membrane. But, only few studies have investigated the colloidal fractions of metals in runoff waters (nanometer to micrometer size range). Therefore, a peri-urban highway experimental site was chosen to sample runoff waters from a bridge with a heavy traffic of 90,000 vehicles per day, during two years. The objective was to study the distribution of selected trace metals (Cd, Cr, Cu, Ni, Pb, Zn) among dissolved, colloidal and particulate fractions, in relation to potential constituents of colloidal and particulate matter (Al, Fe, Mn, Si, organic C). The relationship between physico-chemical water characteristics and chemical elements was investigated and the fractionation of trace metals was quantified by filtration and ultrafiltration. As for another experimental site in Nantes (A11), a high variability of parameters was observed related to extreme concentrations of major elements. The total concentrations of trace metals were in the same range as measured 10 years ago at the same site due to the increase of traffic and constant sources of metals. Metals such as Zn, Ni and Cu were present as colloids in the runoff waters (up to 70% for Cu). Metallic and organic phases were found to be bearing-phases in particulate and colloidal fractions.	Pb, Cr and Cd, which are known to associate with particles, were present entirely in the >8 µm size particles of runoff waters. Zn and Ni were distributed mostly in particulate fractions but with dissolved (<5 kDa) and colloidal fractions up to 30%. The distribution of Cu is quite equal to Zn and Ni, with up to 70% of colloidal Cu. Even if colloidal metals were relatively small compared to other size fractions, total mobility of metals could be enhanced by facilitated transfer of the colloids during infiltration of runoff waters. The association between Fe and Al-bearing phases and Cd, Cr, Zn and Cu was confirmed, just as the link between Cu and organic matter in the <0.45 µm fraction. Mn-bearing phases were pointed out, as the association of Ni with metallic oxy-hydroxides and siliceous particles. This study revealed also that Pb could be more linked to particulate organic matter than adsorbed on metallic oxy-hydroxides. These observations underscore the need for observation of metal-bearing solids phases and characterization of organic phases in runoff waters.	3
[3]	Béchet B., Durin B., Legret M., Le Cloirec P. (2006) *Colloidal speciation of heavy metals in runoff and interstitial waters of a retention/infiltration pond*, Water, Science &Technology, 54(6-7), 307-314	Paper	2006	EN	Yes Both dissolved and particulate fractions (0.45 µm cut-off) have been analysed for major and trace elements. The distribution of metals among particulate, colloidal and dissolved fractions (8 µm and 5 kDa cut-offs) has been also studied. Pollutants : metals (Cd, Cr, Cu, Ni, Pb, Zn)	No	Yes partly	Yes, there are data in tables in the Paper.	As above	The thickness of non-saturated zone and physico-chemical conditions are important parameters to assess the impact of infiltration ponds on water resources with respect to heavy metals transfer. As changes in physico-chemical parameters of solutions have a strong impact on the mobility of colloidal phases in sediments and soils, the colloidal facilitated transfer of heavy metals has to be investigated. Therefore, this study focuses on the characterization of runoff, surface and interstitial waters in a retention/infiltration pond collecting runoff waters of a bridge near Nantes. Physico-chemical parameters and chemical analyses were performed on the waters during about one year. The separation of dissolved and colloidal fractions was carried out by filtration and ultrafiltration for one sample of surface and interstitial waters. Until now, the runoff waters were only filtered at 0.45 mm. The comparison of physico-chemical data shows that the minor variations of runoff water parameters are mitigated in basin and in soils but strong variations impact the composition of interstitial waters. High concentrations of zinc, copper and still of lead are measured in runoff. Lead and cadmium seem to be associated to colloidal and particulate fractions while zinc, copper, nickel and chromium are distributed in all fractions.	The data collection on runoff waters and waters in the retention-infiltration pond at Chevire´ was carried out over about one year. The important findings include the role of sediment in mitigation of the variations of physico-chemical parameters of runoff, if these variations are not too pronounced. Conversely, there is an observed impact on interstitial water. Despite the relatively recent removal of lead from fuels it has been found that the measured concentrations of lead were not markedly different from literature values. Regarding the fractionation of heavy metals in dissolved and colloidal fractions, we conclude that Cd and Pb are associated to fractions above 0.45mm; Zn, Cu, Ni and Cr are present in the different fractions from 3mm to 5 kDa. The colloidal Fe- and Al- oxyhydroxides could be present in fractions above 0.22mm. Manganese is present in all fractions of groundwater. Analysis of future samples will also focus on the content of total organic carbon to better investigate the nature of colloidal phase to try to explain the repartition of Cu and Zn in the colloidal fractions.	3
[4]	Mangani G., Berloni A., Bellucci F., Tatàno F., Maione M. (2005) *Evaluation of the pollutant content in road runoff first flush waters*. *Water, Air, and Soil Pollution*, 160 (1-4), 213-228	Paper	2005	EN	Yes. Pollutants: metals (Al, Zn, Fe, Cu, Pb) and PAHs. Both dissolved and particulate fractions have been analysed for metals. Same thing for PAHs (note that PAHs in the dissolved fraction are always below the detection limit).	No	No	Yes, there are various tables of data in the Paper.	Study area: 29 km long section of the four-lane highway (speed limit 110 km/h) SS/73bis. Study area is located between Urbino and the coastal city of Fano, in Central Italy (Marche region). One summer campaign on the 23rd of August 2002 (after a dry period of 12 days) and one autumn campaign on the 24th of October 2002. Average traffic data is presented in in the paper. A sampling device able to collect the first 10 L of runoff has been used in three different sites (site 1: rural site close to Urbino; site 2: industrialized site near Fano; site 3: strip of road not yet in use during the time of the study). Site 3 allows to discriminate the contribution of traffic from the contribution of the infrastructure itself (asphalt, safety fences, etc.). One summer campaign (on the 23rd of August 2002) and one fall campaign (on the 24th of October 2002) have been carried out.	The study is devoted to the evaluation of the pollutant content in first flush runoff waters from a highway located in Central Italy. Runoff and soil samples have been collected and analysed. Metals are mainly associated with particles. The particulate fractions of site 2 are less polluted (in µg/g) than the particulate fractions of site 1, despite the fact that site 2 is close to an industrialized area. However, the amount of particulate matter in runoff waters in greater for site 2 than for site 1: when metal concentrations are expressed in µg/L, concentrations measured in site 2 are greater than concentrations measured in sites 1 and 3. The lowest metal concentration levels are found in site 3 (no traffic): however, the differences with site 1 are not remarkable. In site 1, PAH concentration are mainly absorbed to the fine fraction of particulate matter, whereas it does not appear to be the case for site 2. PAH concentrations are much lower in site 3. Finally, the concentrations of major ions have also been determined.	Organic and inorganic pollutant content of first flush runoff waters from a non-urban highway located in Central Italy. Temporal and spatial variability of the results are due to the varying site characteristics and rainfall pattern. Concentration ranges of metal contents are consistent with the findings of other European studies. Zn is the most abundant metal whereas Pb is present at low concentrations (sometimes even below the detection limit).	3

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[5]	Legret M. (2001) *Pollution et impact d'eaux de ruissellement de chaussées*. Technical Report LCPC Routes CR 27, 109 pp.	Report	2001	FR	Yes. pH, EC, TSS, chemical oxygen demand, Kjeldahl nitrogen, chloride and sulfate ions, metals, total hydrocarbons, PAHs.	No	Yes	Yes	Various extra-urban experimental sites : 1) A11 highway in the Nantes metropolitan area (France), at the crossing of the Erdre river. This section of the highway displays three lanes (including an emergency lane) in each direction, separated by a central reservation and edged by crash barriers. At the time of the study, mean daily traffic was approximately 12,000 vehicles per day in each direction (7% of trucks). The initial pavement (conventional asphalt) was renovated with a 30 mm thick layer of porous asphalt lying on an impervious surfacing during the 1996 summer. Second experimental campaign after the renovation, between June and November 1997. 2) RN12 four-lane motorway, approximately 50 km west of Paris (France). The mean daily traffic was 21,000 vehicles pey day (10% trucks). The tread of the north carriageway (from Paris to Dreux) is made of porous asphalt whereas the south tread is impervious. Experimental campaign between September and December 1997, on both sides of the motorway. 3) A1 highway, Wancourt rest area, near Arras (France). Experimental campaign between January and June 1997.	The campaign carried out between March 1995 and February 1996 on the A11 highway showed that the total HC content of runoff water was quite high (between 0,14 and 4,2 mg/L, mean 1.2 mg/L). PAH concentrations were low (< 100 ng/L); only fluoranthene and benzo[ghi]perylene were above the detection limit. For trace metals, the most important concentrations were for Zn and Pb. Cu and Cd content were generally quite low. TSS, Pb, Cd and Zn concentrations were higher in winter, probably due to the use of de-icing agents. pH always remained close to 7, EC was strongly dependent on the season (190 µS/cm in summer, 3170 µS/cm in winter), as TSS (mean TSS content of 71 mg/L, but higher in winter) and chloride and sulfate ion concentrations (respectively equal to 1012 mg/L and 93 mg/L during the winter period). Nitrogen concentrations were consistently low. 1997 campaign on the A11 highway (after the replacement of the impervious tread by a porous asphalt layer): removal rates computed by comparison with the results obtained during the first campaign can be high: 90% for the total HC, 94% for TSS and between 21% (Cu) and 74% (Pb) for trace metals. The campaign on the RN12 motorway also showed a significant removal rate of total HC, TSS, Cu and Cd than can be attributed to the porous asphalt. However, Pb and Zn do not seem to be retained by the pavement of the RN12 motorway (clogging?). This result is at odds with the campaigns carried out on the A11 highway. Runoff waters have also been sampled (pH, EC, HC, chemical oxygen demand, TSS and trace metals) in two sites located near the Wancourt rest area, on the A1 highway.	The comparison of the numerous studies presented in this Report shows the type of pavement (impervious or porous) affects the quality of highway runoff waters. The removal rate associated with a porous pavement can be quite important: between 20 and 75% for metals, more than 85% for TSS and approximately 90% for HC. These removal rates are mostly due to the retention of the fine particles by the porous pavement. Metals are mostly found under particulate form, except for zinc. The season has a huge impact on the contaminant contents. Moreover, the results obtained depend greatly on the rainfall event, whatever the pollutant and the indicator selected to express the content of the sample (molar concentration, mass concentration, flux, dissolved/particulate proportions...). This variability cannot be statistically explained by simple data, like the precipitation height, the rainfall intensity or the duration of the dry period preceding the event. Complex mechanisms are likely at play.	5
[6]	Kayhanian M., Fruchtman B., Gulliver J., Montanaro C., Ranieri E., Wuertz S. (2012) *Review of highway runoff characteristics: Comparative analysis and universal implications*. *Water Research,* 46, 6609-6624	Paper	2012	EN	Metastudy	No	No	Yes. Tables of data in the Paper.	No specific site. Review based on different peer-reviewed Papers. This review summarizes and compares different highway runoff characterization studies performed in Europe, North America, East Asia and Australia / New Zealand.	Historical trends, first flush effects, pollutant form (dissolved vs. particulate) and surrogate water quality parameters are discussed. All referenced Papers include data on physical site characteristics (number of highway lanes, pavement type, fraction of impervious area, annual average daily traffic, drainage area and land use) and hydrological characteristics. Automatic flow weighted composite sampling was predominantly used but grab sampling was also employed sometimes. The detection limit was the most variable parameter: values ranging between 0.5 and 50 µg/L have been Reported. Aggregate water quality parameters, metals, nutrients and PAHs have been summarized. The most commonly measured aggregate parameters are TSS and chemical oxygen demand. The concentrations of Cd, Cr, Cu, Pb, Ni and Zn have been Reported in the majority of the studies, whereas the most frequent analysis done on nutrients were TKN or total N and total P. PAHs, herbicides and pesticides have been less studied. This metastudy demonstrates a massive reduction of Pb concentration in highway runoff linked to the leaded gasoline regulation. However, there is no clear decrease nor increase of other metal contaminants. The existence of a first flush effect has been universally recognized. The partitioning of pollutants shows that higher metal concentrations are generally associated with smaller particles. Pb, Al, Fe, As, Cd and Cr are mostly in particulate form, whereas Zn, Cu and Ni are mostly to be found in dissolved form. There is a strong correlation between TSS, TDS, total organic carbon, Fe and 13 others contaminants and water quality parameters (turbidity, oil and grease, total HC, dissolved organic carbon, TKN, EC, chloride ion, Cd, Cr, Cu, Ni, Pb, Zn).	Most studies provided new data on some metal contaminants and standard water quality parameters . Fewer data are Reported on nutrients, PAHs, herbicides and pesticides. The median concentration of most pollutants was generally 20-30% higher in Europe than in North America. Most metal pollutants and phosphorus are associated with particles (with some inconsistencies for Cu, Zn , Ni and P which are shown to be mostly in dissolved form in some studies). Lower molecular weight PAHs are sometimes measured in dissolved form. Some surrogate water quality parameters may be used to reduce the monitoring effort and the associated analytical costs.	5
[7]	Stagge J., David A., Jamil E., Kim H. (2012) *Performance of grass swales for improving water quality from highway runoff, Water Research*, 46, 6731-6742	Paper	2012	EN	Yes	No	No	Yes, there are tables of data in the Paper.	MD Route 32, a four-lane highway near Savage, Maryland (USA). The area adjacent to the highway is a wooded residential development, but the roadway is raised so runoff is generated only by the highway. Assessed water quality parameters were: TSS, nitrate, nitrite, TKN, total phosphorus, chloride, lead, copper and cadmium.	This study is devoted to the performance of grass swales for treating highway runoff. Grass swales are known to provide water quality enhancement services. They are particularly effective in reducing TSS and some metals, especially zinc. In order to evaluate the water quality performance of grass sales, various analysis have been performed on the influent water coming from the highway (these are the analysis that matter the most for us given the scope of the PROPER project) and on the effluent water released by the swales. 45 storm events, spanning a 4.5 year period (November 2004 to May 2006 for the 18 first storm events, and April 2007 to July 2009 for the last 27 storm events), have been monitored. Flow data and water samples were taken during 6-8 hours at regular intervals for each event (12 samples per event). The range of mean event concentrations is shown in the paper 2 for TSS, total nitrogen, nitrate, nitrite, TKN, total phosphorus, chloride, lead, copper, zinc, cadmium (columns HWY and HWY-CD).	The focus of the study is the performance of field-scale grass swales that receive lateral runoff water coming from a highway. The goal was also to characterize the effect of two alternative designs (inclusion of a grass filter and vegetated check dams). The swale indeed reduced pollutant mass and average concentration for TSS, lead, copper, zinc and cadmium. The removal rate was variable for nutrients (seasonal effect), except for nitrite. This study shows that the presence of a grass pre-treatment filter or vegetated check dams has a negligible effect with respect to water quality. Despite its focus on the performance of swales, this study provides relevant chemical data of runoff generated by a North American highway.	3
[8]	Piguet P. (2007) *Road runoff over the shoulder diffuse infiltration real-scale experimentation and optimization*, PhD Thesis, EPFL, Lausanne, Switzerland	Thesis	2007	EN	Yes	No	Yes	Yes	The RC263c road is a two-way road located in the canton of Vaud (Switzerland), between the municipalities of Champagnes and Grandson. The monitored section of the road is 95 m long. It is located near lieu-dit La Deude (municipality of Grandson). This section is approximately oriented along a north/south axis and is smoothly inclined eastward (3% transversal slope) for runoff evacuation purposes. Traffic has been measured from January 2004 to the end of September 2005. The road is mainly used one way: 280 vehicles/day on the western lane and 1800 on the eastern lane. Peak traffic charge reached 5800 vehicles one day in June 2004. 112 natural rainfall events have been recorded during the course of this study. An additional artificial rainfall event (named artificial test n°2) has also been performed with water collected in a polyethylene waterproofed roof for chemical experiments. This event mimicked a typical rainfall occurring in summer (mean rainfall intensity of 23 mm/h during 15 minutes).	A new method of road runoff management has been devised an tested in a real-scale experiment undertaken in Switzerland. This concept is based on the diffuse infiltration of road runoff in the infiltration slope edging the road shoulder. Turbidity, TOC, EC and temperature have been continuously monitored. Runoff quality analysis have been performed for 6 families of contaminants: MTE, PAH, Cx (aliphatic hydrocarbons), BTEX, MTBE and PCB. Fractionations have been performed. The road runoff content during the artificial event has been thoroughly investigated. The first flush produces a peak of EC and MTE concentrations. Mobile MTE are always transported, whatever the rainfall intensity, whereas elements with low mobility are preferentially transported during high flow periods but the highest concentrations do not coincide with the highest precipitation intensity since the small particles and colloids transport much more contaminants than the bigger ones. All PAH are present in the runoff samples. Comparison between the measurements obtained with the artificial event and measurements made during 4 natural events shows that MTE concentrations were very different from one event to another. MTE are mostly transported on particles (the most mobile elements being B, Br and Mo). The PAH with the highest molecular weights have the highest concentrations.	Among the specificities of this study, one can mention that the monitored road segment was new. The initial pollution was thus negligible. Two lysimeters allowed to perform in situ infiltration experiments and to calculate water and contaminants mass balances. Moreover, the underlying aquifer has been monitored.The concentrations of mobile MTE and PAH were correlated with EC. Less mobile contaminants were more correlated with turbidity.This thesis demonstrates that the presence of an infiltration slope improves the quality of the water: all contaminant concentrations are greatly reduced, and some pollutants even become undetectable. The environmental advantages of this new concept of roads are very clear.	5

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[9]	Tromp (2005) *Helofyteninfiltratiesystemen voor zuivering van wegwater. Onderzoek naar het milieurendement van een Helofyteninfiltratiesloot langs de A1 in 't Gooi.* Utrecht University, July, 2005	Report	2005	NL	Monitoring study on the effectivity of a helophyte filter next to the highway A1 in the Netherlands. It includes information on concentrations of PAHs and heavy metals in runoff water and in influent/effluent of the filter and influent/effluent of drains.	The Report contains a mass balance based on measurements. No additional modelling.	No	Yes. Concentrations (4 week averages during 1,5 years) in runoff, influent and effluent (11 PAHs 6 and metals).	The monitoring site is located at highway A1 in the Netherlands, near 't Gooi. The road consist of porous asphalt, which was cleaned 4 times during the monitoring period. The precipitation varied between 0 mm and 180 mm in a 4-week period (with a total of 800-1000 mm per year). Traffic intensity was approximately 56000 vehicles per day, of which 11% trucks.	Monitoring study on the effectivity of a helophyte filter next to the highway A1 in the Netherlands. This road consists of porous asphalt and part of the pollutants are removed from the runoff water because of the cleaning of porous asphalt. This Report includes information on concentrations of 11 PAHs and 6 heavy metals in runoff water and in influent/effluent of the filter and influent/effluent of drains (4-week averages for a 1,5 year period). A mass balance of the pollutants is made: Data for the first year: First a part of the pollutants accumulates in the porous asphalt and is removed by cleaning (34 g PAH/ha, 459 g Cu/ha and 1428 g Zn/ha). The remaining part of pollutants enter a drain and part of the pollutants accumulate in the drain (and is also removed by cleaning) (37 g PAH/ha, 95 g Cu/ha and 410 g Zn/ha). After that, the pollutants enter the helophyte filter (1 g PAH/ha) where most of the remaining pollutants is removed (-94% for PAH, -22% for Cu and -59% for Zn).	This Report consist of multiple conclusions. The most important ones are: Concentrations of PAHs, copper and zinc in runoff water are higher than the water quality standards. PAH, copper and zinc deposit in drains. If this is cleaned yearly, this will result in a lower amount of pollutants that ends up in the helophyte filter. The removal efficiency of the helophyte filter was 93% for PAHs, 18% for copper and 56% for zinc (2-year average)	3
[10]	de Best J., Vergouwen A., Schipper P. (2003) *Run-off en verwaaiing Provinciale wegen. Onderzoek naar de risico's voor bodem en water en richtlijnen voor weg en waterbeheer. Documentnummer 13/99044811. Grontmij en ECN*. 1 april 2002.	Report	2002	NL	Literature review on road run-off on secondary roads (with data on concentrations from several older monitoring studies)	No modelling	No	Yes. From older monitoring studies (concentrations in run-off, groundwater and soil)	Several sites in the Netherlands, both highways and secondary roads. Roads with porous asphalt and road with regular asphalt.	This study describes the pathways (runoff and spray) of pollutants to soil and surface water. The focus is on 10 PAH and metals (Cd, Cr, Cu, Ni, Pb, Zn). On highways with porous asphalt, pollutants mainly enter the environment through run-off, while on highways and secondary roads with regular asphalt, pollutants mainly enter the environment through spray. The amount of emissions from highways with porous asphalt is lower than emissions from regular asphalt. Pollutant concentrations in groundwater show no difference between the locations near the road and locations further away. The emissions from the road show no clear effect on groundwater. Pollutant concentrations in surface water depend on the construction of the road side. On a highway or secondary road with closed asphalt, 50-90% of the metals and PAHs in the run-off water is bound to particles. Most of the pollutants from highways enter the environment through spreading by wind, while the pollutants from secondary roads enter the environment by spray and by direct run-off. The difference is mainly caused by the absence of an emergency lane in secondary roads. Loads are affected by the first-flush-effect (higher loads during a rain event after a dry period), use of the emergency lane, traffic intensity, precipitation intensity, etc.	Emissions of PAH and metals are lower from roads with porous asphalt. Emissions from zinc are the highest (compared to the other pollutants). Runoff mainly influences the road bankin the first few meters. Elevated concentrations of metals and PAHs in the soil have been found in 5-10 meter from the road (mainly in the top lyer (10 cm) of the soil). No elevated concentrations in the groundwater were found (except for PAH). Concentrations in the surface water are affected by the way the run-off is removed (drains, direct run-off into the surface water, etc) and by the way pollutants can enter the water via dispersion by wind (size of the water body, factors that influence the wind (eg trees), etc)	3
[11]	Brongers, I., 2010. *Jaarverslag 2009 monitoring WVO-vergunning A27. Terugblik 2001-2009. Rijkswaterstaat*, 19 april 2010.	Report	2010	NL	Yes. 5 metals and 16 PAHs measured at the discharge and in the water soil of sedimentation ponds.	No	No. Only a comparison with permits	yes. Concentrations at the discharge of a sedimentation pond and of the water soil	Highway A27 in the Netherlands (Flevoland province).	This Report describes the results of measurements at the discharge and the water soil of several sedimentation ponds next to the highway A27, and this is compared to the concentrations that are allowed in the permit. 5 metals and 16 APH have been measured (of which some remained below the detection limit). Also the concentrations in the surface water in 4 locations near the A27 highway have been measured for metals and PAH.	The water quality at the discharges of the sedimentation ponds were compared to the permits and it is concluded that the limits in the permit were exceeded only in a few occasions.	3
[12]	van den Berg, G.A., Hunneman, H., Langemeijer, H.D., 2009. *Emissie van verontreinigingen door run-off en verwaaiing van dunne deklagen. Pilot Noordoostpolder*. KWR 09.072. December 2009.	Report	2009	NL	Yes. Concentrations of 9 metals and 16 PAHs if spray (at 0.5, 3 and 50 meter of the road) and runoff have been measured.	No	No	Yes. Concentrations of 9 metals and 16 PAHs if spray (at 0.5, 3 and 50 meter of the road) and runoff have been measured.	Highway A6, near Emmeloord in the Netherlands. 3 experimental locations on this highway with 3 different types of (open) asphalt	Measured concentrations of concentrations in spray (at 0.5, 3 and 50 meter distance of the road) and concentrations in runoff. Concentrations of PAH in spray were often lower than the detection limit, while concentrations of zinc, copper and lead were often higher than the detection limit (and sometimes higher than environmental limits). Concentrations of PAH in runoff were often lower than the detection limit, while concentrations of zinc, copper and lead were often higher than the detection limit (and often higher than environmental limits)	PAHs in runoff do not exceed the environmental limits, while zinc and copper in runoff often exceed the environmental limit. Runoff water needs some kind of after treatment. (either infiltration in the soil or any either after treatment). There was no significant difference between the three types of asphalt.	3
[13]	van Bohemen H., Janssen van de Laak W. (2003) *The Influence of Road Infrastructure and Traffic on Soil, Water and Air,* Environmental Management, 31(1), 50-68	Paper	2003	EN	Review of older measurements on runoff and spray (in the nineties)	No	No	Yes. Mass flow of 6 metals and 10 PAHs in runoff and spray (in g/week/m road length)	Measurement at 6 highways (in the nineties). Three highways with regular asphalt and three highways with porous asphalt. Traffic intensity varies between 21000 and 90000 cars per day.	This Paper describes the sources and the dispersion of pollutants in the road side environment. It also discusses possible treatment options.	Along regular asphalt roads, wind spray is the main manner of spreading. Along porous asphalt roads, the relative significance of spray is strongly reduced. The mass flow along porous asphalt roads is 1-2 orders of magnitude lower than along regular asphalt roads. There is no clear relationship between mass flow and traffic intensity. Pollutants appear to be restricted to the top layer (30-40 cm) of the soil and it is restricted to 10 meter from the road. The groundwater showed some exceedance of the limits for chromium.	3
[14]	van Duijnhoven, N. and den Hamer, D., 2013. Case studie afstromend wegwater. Vergelijking metingen met de EmissieRegistratie. Deltares Report 1208038-000-ZWS-0005.	Report	2013	NL	Literature study of older monitoring studies (de Best, 2003, Tromp, 2005, van den Berg, 2009, Berendsen, 2006)	Yes. Comparison between the calculated emissions (based on an emission factor per vehicle km) and the actual measured concentrations.	No	Yes	2 highways (A59 and A27) and 2 secondary roads (N199 and N413).	This Report compares the estimated emissions (based on emissions factors per vehicle kilometre for tire wear, road wear, brake wear and oil leakage) with measured concentrations in runoff.	Reported emissions from cadmium, chromium and nickel are much lower than the amount that can be calculated from concentrations in runoff (except for nickel in A59). Also the Reported emissions from copper and lead are lower than the amount that can be calculated from runoff, but the difference is less than for the Cd, Cr and Ni. Reported emissions of zinc is in line with the amount that can be calculated from the concentrations in runoff (factor 2 difference). Reported emissions of PAHs are much higher than the amount that can be calculated from the runoff concentrations.	3
[15]	van Duijnhoven, N., Klein, J., den Hamer, D., 2013. Update verontreinigingsbeeld afstromend wegwater. Deltares rapport 1208038-000-ZWS-0003.	Report	2013	NL	Literature study of older monitoring studies (de Best, 2003, Tromp, 2005, van den Berg, 2009, Berendsen, 2006)			yes	4 highways and 2 secondary roads in the Netherlands. For each road there is traffic intensity, asphalt type. Average concentrations in run-off	This Report describes the studies that have been done on 4 highways and 2 secondary roads in the Netherlands. It summarizes the measurements that has been done on run-off, or the discharge of sedimentation ponds. Metals and total PAH have been analysed.	The differences between the roads are large and it was therefore not possible to draw a conclusion for the entire country. Concentrations in runoff from regular asphalt highways and secondary roads are larger than concentrations in runoff from porous asphalt highways and secondary roads.	2
[16]	Delates and TNO, 2016. Bandenslijtage wegverkeer. Emissieschattingen diffuse bronnen Emissieregistratie. BVersie mei 2016.	Factsheet	2016	NL	No	Yes. Model to calculate emissions to surface water and sewer on a national scale	No	Emission factors per vehicle kilometre	Netherlands	This factsheet describes how national emissions from tire wear are calculated. Average emissions factors per vehicle km are used to calculate the emissions (varying for different vehicle types). The emission factors are corrected for reduction due to the amount of porous asphalt that is used. It is assumed that 90% of the large particulates end up in the soil, while 10% of the large particulates end up in the surface water (for highways and secondary roads).		2

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[17]	Delates and TNO, 2016. Lekkage motorolie. Emissieschattingen diffuse bronnen Emissieregistratie. BVersie mei 2016.	Factsheet	2016	NL	No	Yes. Model to calculate emissions to surface water and sewer on a national scale	No	Emission factors per vehicle kilometre	Netherlands	This factsheet describes how national emissions from leakage of oil are calculated. Average emissions factors per vehicle km are used to calculate the emissions (10 mg oil per vehicle km, combined with a profile of metals and PAHs in the oil). The emission factors are corrected for reduction due to the amount of porous asphalt that is used. It is assumed that 90% of the oil end up in the soil and 10% of the oil end up in the surface water (for highways and secondary roads).		2
[18]	Delates and TNO, 2016. Wegdekslijtage ten gevolge van het wegverkeer. Emissieschattingen diffuse bronnen Emissieregistratie. BVersie mei 2016.	Factsheet	2016	NL	No	Yes. Model to calculate emissions to surface water and sewer on a national scale	No	Emission factors per vehicle kilometre	Netherlands	This factsheet describes how national emissions from road wear are calculated. Average emissions factors per vehicle km are used to calculate the emissions (varying for different vehicle types). It is assumed that 90% of the large particulates end up in the soil, while 10% of the large particulates end up in the surface water (for highways and secondary roads).		2
[19]	Delates and TNO, 2016. Remslijtage. Emissieschattingen diffuse bronnen Emissieregistratie. BVersie mei 2016.	Factsheet	2016	NL	No	Yes. Model to calculate emissions to surface water and sewer on a national scale	No	Emission factors per vehicle kilometre	Netherlands	This factsheet describes how national emissions from brake wear are calculated. Average emissions factors per vehicle km are used to calculate the emissions (varying for different vehicle types). The emission factors are corrected for reduction due to the amount of porous asphalt that is used. It is assumed that 90% of the large particulates end up in the soil, while 10% of the large particulates end up in the surface water (for highways and secondary roads).		2
[20]	MTI, 1997. Bemonsterinig tunnelafstroomwater. Report R97019/929M1037A0/AVE. Februari 1997.	Report	1997	NL	Yes. Concentrations of 6 metals and total PAHs (sum of 6, 10 and 16 PAHs) in tunnel water and tunnel sludge.	No	No	Concentration in tunnel water and tunnel sludge. Mass flux per year.	4 (highway) tunnels in the Netherlands.	This Report describes measurement on concentrations and mass flues of pollutants in tunnels. Measurements on four tunnels were done, including an investigation of the traffic intensity, presence of street furniture, type of asphalt, influence of washing the walls of the tunnel. Additional note: in 2016, water concentrations in these tunnels were analysed again.	The concentrations in the tunnel water cannot be linked to traffic intensity, asphalt type and presence of street furniture. Washing of the tunnel walls does not significantly influence the water quality. Most of the pollution in the tunnel is removed from the tunnel by sludge removal. The amount of metals does not seem to be linked to traffic intensity, but the amount of organic pollutants appear to be linked to traffic intensity.	3
[21]	Dufek J, Svoboda F., Adamec V. (2001) *Stabilization and gradual reduction of environmental load by transport in the Czech Republic,* CDV Report	Report	2001	CZ	Research work focused on the runoff water contamination from highway D1.	No	No	Yes, the Reports is available only in Czech language.	Runoff settling reservoirs (RSRs), which are part of the D1 drainage system, were observed. These are tanks into which collecting sewers are discharged to drain off the runoff water from the highway. In RSRs, suspended particles heavier than water are gravitationally removed as well as liquid phases lighter than water is removed. During the water retention in this reservoirs, the organic matter is partially recovered due to the action of microorganisms. Water from RSRs are representative of the contamination of transport activities.	Samples of water were collected at six runoff settling reservoirs (RSRs) on the D1 motorway at the outflow from these reservoirs. Concentrations of mineral oils were monitored several years in the water samples on the discharge from reservoirs. In one RSR fitted with an output filter for mineral oils, comparison of the mineral oils concentrations was made in the water samples in the reservoir entrance, in the entrance to the filter and in the discharge water from the filter. Mineral oils were observed as a representative of contamination from transportation. For most samples, the mineral oils concentrations were lower in the outflow waters from reservoirs than in the inflow waters (between 13 - 65 %). Most water samples have also did not exceed the limits for the permissible level of mineral oils contamination in water system in the Czech Republic. The results also show that the functionality of the mineral oils sorption filter is problematic. In case, when is the low content of mineral oils in the inflow water to filter, the mineral oils are washed out from the filter and concentration of mineral oils are higher in the outflow water.	This task deals with the problem of D1 highway runoff water contamination collected in the rain settling reservoirs. Samples of water on the inflow and outflow from the reservoirs were sampled at the six sites. The analyses were focused on mineral oils concentrations. In most cases concentrations of mineral oils at the outlet did not exceed the legislative limits for surface water quality in the Czech Republic. In the case of the reservoir equipped with filter for sorption of mineral oils, the results of water sample analyses have shown a problematic filter function. In case, when is the low content of mineral oils in the inflow water to filter, the mineral oils are washed out from the filter and concentration of mineral oils are higher in the outflow water.	3
[22]	Adamec V., Huzlík J., Marešová V., Sucumanová M., Trhlíková B. (2004) *Exploration of the environmental impact of transport,* Research Report No.:CE 801 210 109 Brno: TRC (CZ)	Report	2004	CZ	Research task of Ministry of Transport of the Czech Republic, quality monitoring of runoff waters from highway in retention ponds using two different sampling methods. Contamination level of runoff water samples from the D5 highway was determined in two retention ponds which are designed to capture these waters from the road body.	No	No	Yes, the Report is available only in Czech language.	The sampling localities of Rozvadov and Heřmanova Huť are located on the D5 highway nearby the border with Germany. They have been chosen on the basis of the traffic intensity and the purpose of their use. These are retention ponds for collecting runoff waters from highway. Runoff waters are detained here, suspended particles are settled and water flow to the recipient where they are diluted.	The Report deals with monitoring of runoff waters contamination in two extremely loaded locations on the D5 motorway. In two retention ponds on the highway D5 (Rozvadov and Heřmaova Huť), water contamination was monitored between the year 2002 - 2004. Water sampling was done in two ways: spot sampling and with pasiv sampling using Semipermeable Membrane Devices (SPMD). Concentrations of mineral oils and 16 PAH according to US EPA were monitored. Results showed that the concentration of PAHs in the spot samples ranged from 12 - 190 ng/L and in SPMDs between 1 - 25 ng/L. Mineral oils concentrations were in the range of 0,03 - 1,5 mg/L for spot samples. Results of spot water samples for PAHs showed higher contamination then results of SPMDs. Concentrations in SPMDs had clearly increasing trend, concentrations in spot samples ascilated. The differences are given by the different sampling principles. Spot water samples taken in 2004 were also subjected to ecotoxicology testing at three trophic levels (algae, crustaceans and bacteria). Water samples were, except of two cases, non-toxic.	They are retention ponds used to trap the runoff waters of the motorway body. The monitoring was carried out from 2002 to 2004. Two types of sampling - spot and SPMDs - were applied. PAHs and mineral oils were observed both types of samples. Toxicity tests at three trophic levels (algae, crustaceans, and bacteria) were also applied. The results of PAHs showed slightly polluted waters. Concentration values in spot samples were higher than SPMDs samples. Concentrations of PAHs in the spot samples showed a fluctuating trend, while PAHs concentrations in SPMDs showed clearly increasing trend. Due to the type of sampling, the results of SPMDs can be considered more accurate. In this case, only PAHs contained in the water are captured in the triolein within the membrane, while in the spot sampling the analyses determine not only the PAHs contained in the water but also the PAHs adherents on the solid particles suspended in the water samples. The results of the toxicity tests showed that the samples were, except two cases, non-toxic.	3
[23]	Marešová V., Sucumanová M., Marvanová S., Huzlík J., Adamec V. (2002) *Evaluation of waters contaminated from the roads using ecotoxicological biotests and chemical analysis, SETAC International Conference 2002*	Poster	2002	EN	The study was supported by the Czech Ministry of Transport as research project MD ČR 002. It determined contamination of runoff waters from motorways and collected in the receiving collectors, small settlers.	No	No	Yes, but limited	Five places of water streams crossing the motorway D1 (Prague-Brno-Vyskov) were chosen for the sampling. These are small reservoirs (settlers) that collect surface water from motorway. Water washed away form the road surface are in the settler retained, solid impurities and suspended particles are settled and an excess of runoff waters are freely discharged from the settlers to a water stream or to the soil.	Water and sediment samples from the settlers were analysed for polyaromatic hydrocarbons (PAHs), nitro-polyaromatic hydrocarbons (nitro-PAHs) and mineral oils. Ecotoxicological tests on bacteria (Microtox), crustaceans (Thamnotox) and algae (Scenedesmus quadricauda) were performed. Several samples which showed toxicity in some of the tests were then analysed for the content of chosen metals. Toxicity test showed that the most sensitive test for these types of waters was the test on crustacean Thamnocephalus platyurus.Pore water of sediment samples were generally more toxic than water samples. In several water samples algal test showed slight toxicity and the Microtox test showed toxicity only in pore water from one locality. Concentrations of mineral oils was more higher in sediments then in water samples. Concentrations of PAHs are more concentrated in sediments similary as mineral oils. Both the non-toxic samples and the samples which showed toxicity in some of the tests were used for selected heavy metals concentrations determination. Most heavy metals entering aquatic system are associated with particles and accumulate in sediments. Metals Cr, Cu, As, Cd, Pb, Ni and Zn showed higher concentrations which we can consider to slightly pollution or pollution water.	This study deals with water contamination caused by traffic using both chemical analysis of pollutants expected to come from traffic and examination of complex effects by means of simple ecotoxicological biotests. Identification of the relation between chemical pollutants and ecotoxicological biotests is generally difficult. Possible connection could be suggested between the crustacean test and the amount of arsenic in the one case of water samples from one locality. Concerning PAHs and mineral oils, the results do not suggest any connection with the toxicity. Concerning the other samples, analogical relations were not suggested.	3

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[24]	Beránkova D., Brtníková H., Kupec J., Prax P., Huzlík J. (2008) *Pollution of the highways runoff,* Transactions on transport sciences, vol.1, n. 2	Paper	2008	EN	Monitoring within the research project of the Ministry of Transport of the Czech Republic. Basic chemical parameters were determined in water samples and sediment extraction substances, ecotoxicity tests have also been carried out. Analysed substances were Pb, Cd, Ni, Hg, Cr, Cu, Zn, Cl, Hydrocarbons C10-C40 and 6 PAHs.	No		Yes, data is available	Monitoring was performed in the period of 2005 – 2007 on the highway D1 Praha-Brno between 61.5 and 81.5 km. Intensity of transport on this stretch is approximately 40000/day. Water quality was monitored in the inflow to the runoff settling reservoirs and in adjacent recipient. Also samples of snow and sediment on the bottom of these basins were analysed. The second monitored profile with the same density of traffic with automatic sampling device was situated on the highway bridge on the 149.5 km of D1. The third monitored area was the new stretch at 233 km of highway D1 with a very low intensity, and which has been operating only for a short period.	This Paper collates the final results of the project dealing with the quantity and quality of highways runoff. Field investigation was carried out through the period 2005 - 2007 on several stretches of D1 highway Praha - Brno. Low contents of the EU priority dangerous substances in surface runoff water, which depends on the character of sampling and level of traffic intensity, were found. An impact on the water ecosystem, mainly on the algae Scenedesmus quadricauda, was confirmed through ecotoxicity testing. The measurement of precipitation and outflow has also brought findings about the variability of runoff coefficient in this built up transport area.	The negative impact of runoff from highways on the recipients and water bodies also enhances a certain amount of priority dangerous substance as specified by EU. High concentrations of chloride from winter road maintenance increase ecotoxicity of water, which was demonstrated by testing on algae. During intensive rainfall small receiving bodies flood; polluted suspended solids are diluted and transported into the river basin. Similarly, as in other European states, it seems to be necessary to monitor and control this potential strain of pollution along the highways and to do the best management practices and to project and implement protective measures against it.	3
[25]	Rozkošný M., Novotný R., Beránková D., Kriška M., Hudcová T. (2014) *Development and changes in characteristics of infiltration and retention facilities fo transport infrastructure and paved area surface run-off treatment*, Transactions on Transport Sciences, vol. 7(4)	Paper	2014	EN	Runoff water monitoring of the urban roads and car parking places within research project of the Technology Agency of the Czech Republic. There were monitored cleaning effects of selected facilities for the retention of pollutants from the group of PAHs, petroleum substances and metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) .	No		Yes, data is available	Parking place located in Brno-Bohunice was chosen for monitoring. The first furrow is located in the upper part, in 2008 and 2009 less used of the car parking place . The second furrow is in the lower part of the car park, which was gradually more and more used in connection with the ongoing completion of the campus premises and the shopping centre in 2008. Both parts of the car parking were fully used for parking during the period 2013 – 2014. The furrow “Bohunice 1” surface area was 121 m^2 by in-situ measurement and the corresponding area of the car parking theoretically drained by this furrow was 592 m2. The surface area of the other furrow “Bohunice 2" is 195 m^2 and the corresponding area of the car park theoretically drained by this furrow is 1,040 m^2. In the drainage shafts, into which piping drains of the particular furrows flow, collecting sampling containers made of polypropylene were placed, where the seepage water was trapped.	The article presents the results of the research aimed at monitoring the retention, treatment and infiltration of surface run-off from transport infrastructure and paved areas (urban roads and car parkings) in the Brno city area between the years 2008 and 2014. The conclusions from the analysis of the cleaning effect of selected facilities for the retention of pollutants from the group of PAHs, petroleum substances, Cl and metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) are also presented. The article includes information about the changes in the infiltration characteristics of the monitored infiltration and retention facilities in the period 2008 – 2014.	The results show that the surface run-off at the monitored area currently contains less pollution, especially metals. The amount of monitored pollutants was higher in the surface run-off in transport infrastructure samples than in the rainwater samples, which presents a certain impact of traffic on the run-off water quality. The contamination of outflows from the monitored retention facilities has been in the same range of values since 2008. The retention facilities has been showing high elimination of monitored pollutants, but as was shown in the case of C10-C40 substances, an appropriate management is necessary (*e.g.* sediment disposal) to prevent secondary contamination of outflow water.	3
[26]	EIASERVIS (2004) *Real concentrations of chloride ions in surface water from roads on 10 selected road sections in winter 2003/04*. EIA SERVIS s.r.o., Institute of Hydrobiology, Czech Academy of Sciences, České Budějovice and Faculty of Biology, Directorate of Roads and Motorways, Czech Republic	Report	2004	CZ	An ecological study deals with chlorides contamination of surface and ground water due to their application to the road surface during winter maintenance.	No		Yes, but limited	The concentration of chloride ions were monitored on ten selected sections of the road I / 20 České Budějovice - Vodňany and III / 12253 Dubné - Záboří. It was places where the watercourse crossing the roads. The samples were taken above and below crossings with roads.	In winter 2003/2004, the impact of chemical maintenance of roads I / 20 České Budějovice - Bosňany and III / 12253 Dubné - Záboří on the quality of crossed water streams (runoff inflow to the stream or river) was monitored. In total 449 pairs of water samples (above and below the road crossing) were taken, of which 335 sample pairs in January - March 2004 and 114 pairs of samples in the period April - September 2004.	Results demonstrated that chemical maintenance of the roads has resulted in a statistically significant increase in the concentration of chloride ions in watercourses crossing the road. The average increase in the concentration of chloride ions in the streams undercrossing roads ranged from 0.5 to 20.1 mg / l, an increase of 2.9 - 46.7 %. Only in one locality the average increase in chloride ion concentration was 60.4 mg / l (128.2 %). This was apparently due to the supply of chloride ions from a residential area from a nearby village. The most important findings from the 2003/2004 winter study are the fact that up to 97 % of chlorides applied on the road do not flow through the cross-flow (recipient), but they are absorb by the soil and rock environment.	3
[27]	Vuhnálek V., UmŽík R., Riegertová A. a kol. Concentration of chloride ions in soils, surface and ground water in the corridor of road I / 20 České Budějovice - Vodňany in winter 2005/2006, Environmental service Inc. in cooperation with Institute of Hydrobiology - Academy of Sciences of the Czech Republic; Faculty of Biology - South Bohemia University	Report	2007	CZ	An ecological study deals with chlorides contamination of surface and ground water due to their application to the road surface during winter maintenance. Study follows previous work in 2003 and 2004.	No		Yes, data is available	Chloride concentration monitoring was carried out in the I / 20 road section between České Budějovice (MÚK České Vrbné) and Vodňany. In total, six sites of crossing waterways with roads were monitored. In each of the profiles, samples of water were taken were taken in the watercourse above and below the road crossing (about 25-100 m from the road) to determine the concentration of chloride ions .	The concentration of chloride ions in the I / 20 Ceske Budejovice - Vodnany corridor in cross-water courses (recepies), in the soil around the road and in the underground water around the road were monitored. The main objective of the study was to evaluate the real direct effects of chemical road maintenance in the winter season on the watercourses (runoff inflow to the stream or river), soil and groundwater. Monitoring was performed in period between December 2005 and December 2006. Sampling interval was modified on the basis of actual weather and de-icing agents application. Sampling was performed twice a week in snowing period between December 2005 and the beginning of April 2006. Than the monitoring was performed once a week in period between April and May 2006, once per month in period between from June to October 2003 and once in a month in November and December 2006.	From the seasonal trend of chloride concentrations in watercourses above and below the road crossing, it is clear that the contribution of chemical road maintenance to the chloride concentration in the flow varies across the profiles. The average values of the difference in chloride concentrations (below - above) during the winter period from December 2005 to March 2006 were in the range of 0.64 - 7.16 mg / l. Chlorides were monitored at localities even in summer, April - December 2006. Differences in concentrations above and below were in the range 0.33 - 6.33 mg / l. The results show that chlorides from the road to cross-water flows occur both in winter and in summer. Part of the applied salt spreads are then taken to waterways immediately after their application to the road (mostly during the melting phase), part remains in the body of the road or its surroundings during the subsequent summer part of the year, and it gradually gets into the surface water.	3
[28]	Huzlík J., Jandová V., Adamec V. (2004) *Methodology of water quality assessment and rock environment in the vicinity of transport networks*, Czech Ministry of Transport (No. MD ČR 002 - Research of the environmental burden of transport).	Report	2004	CZ	The methodology was developed in the framework of the project "Research of the environmental burden of transport". It is intended for application in the design of measures aimed at reducing the environmental compartments of the environment.	Yes, the potential impact on the quality of the environment of the road surroundings is defined. Sites with the highest pollution risk are identified, and the optimal number of monitoring sites is determined.	No	No	The sampling localities are determined based on the application of the methodology for the defined area (republic, county, district). After selecting the sites with the highest risk of traffic-related contamination of waters and soils/rocks, an optimal number of monitoring sites is set.	The methodology calculates potential risk of impact of transport on water and the rock environment quality in defined road section. The risk is distinguished by grades 1-5, where 1 is defined as very low risk and 5 as a very high risk of pollution. These are the potential risk levels that serve to build a sampling site network (the monitoring network) to prove the actual contamination of the selected sections of the relevant communications. From environmental protection point of view, it is the most important to verify the level of contamination of the road sections, which was assigned with mark 5, ie a very high risk of pollution.	The methodology application defines a monitoring network that is composed of sampling sites. These are determined using eight basic parameters that describe each section of the road (or railway) including its surroundings. These parameters include characterization of road (or railway) surroundings namely type of drainage and characterization of the collector of rock environment (Horizontal risk of contamination), water management function of the land cover (Vertical risk of pollution), water management significance of the collector with the assumption of the use of groundwater, degree of protection of water and road (or railway) characteristics namely carriage under the European Agreement on the International Carriage of Dangerous Goods, crossing watercourses with communications, Intensity of traffic and number of accident on defined road section. The result is the determination of the normalized potential impact of road (railway) transport on water quality and the rock environment expressed by numerical indicator. Based on this indicator, sites with the highest risk of pollution are defined and contamination monitoring network is set up.	3

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[29]	Barrett M., Malina F., Charbeneau, R., Ward G. (1995) *Characterization of highway runoff in the Austin Texas area,* Technical report CRWR 263, University of Texas at Austin	Report	1995	EN	characterisation of the quantity and quality of runoff from highways in the Austin, Texas area, and estimation of the pollutant loads resulting from runoff from existing and newly completed sections of highway under different vehicle use patterns	No	No	Yes	Sampling sites selected for variations in daily traffic flow, surrounding land use, and drainage area. 12 mths monitoring during which 444mm rainfall; automatic flow and sampling systems; runoff coefficients calculated; flow weighted composite samples; samples analysed for: turbidity, total and volatile suspended solids (TSS and VSS), 5-Day Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), oil and grease (O&G), nutrients (nitrate and total phosphorus), heavy metals (iron, lead, cadmium, nickel, zinc, and copper), and bacteria (total coliform, fecal coliform, and fecal streptococcus). data presented as EMCs and median concentrations and estimated annual pollutant loadings (kg/ha)	Water quality of highway runoff in the Austin, Texas area was determined by monitoring runoff at three locations on MoPac, which represented different daily traffic volumes, surrounding land uses, and highway drainage system types; 35th street = high traffic site (60,000 vehicles per day), Convict Hill = low traffic site (8700 vehicles per day); Runoff flow rates were measured and samples were collected automatically during rainfall events (doesn't state how many).	Highest concentrations of all constituents were measured at the high traffic site. Data comparable to median values compiled in a nationwide study of highway runoff quality. The total load of pollutant discharged is more important for estimating water quality impacts for many receiving waters than is concentration. Little adverse impact would be expected for all but the most sensitive receiving waters based on the quantity and quality of highway runoff generated during storms. The water quality of highway runoff is generally similar to that Reported for urban runoff, and does not contain appreciably higher concentrations of toxic metals or oil and grease. The impacts of highway runoff alone, like many other nonpoint sources of pollution generally are not significant when considered singly, but may result in degradation of water quality when combined with other sources such as urban runoff. A first flush effect (i.e., higher pollutant concentrations at the beginning of an event) was very evident during selected events, but was generally limited to a small volume. When all monitored events were considered, the overall effect was small or negligible. The concentrations appeared to be affected by changes in traffic volume, rainfall intensity, and other factors. In addition, vehicles provided a continuous input of pollutants to the road surface and runoff for the duration of runoff events. In considering the potential effectiveness of storm water treatment systems, constant concentrations for individual storm events should be assumed.	3
[30]	CALTRANS (2003) *Discharge Characterization Study Report,* California Departmanet of Transportation CTSW-RT-03-065.51.4	Report	2003	EN	California-wide monitoring of Highways, Maintenance stations, Park and ride lots, Rest areas, toll plazas, weigh stations.	No	No	Yes for highways only see Table 3-2 on page 42; and Table 2.2 on page 28 Site Characteristics and Events Monitored	Automated monitoring equipment to collect flow-proportioned composite samples. 39 sites; 684 events over a 10 year period; analysed for: conventional parameters, total petroleum hydrocarbons, trace metals, nutrients, pesticides and herbicides, and semi-volatile organic compounds. ADDT 1800-259000; catchment = 0.08-5.9 ha	Multiple Linear Regression (MLR) analysis was employed to assess the factors that influence the quality of runoff from transportation facilities. The results indicated that several environmental and site-specific factors have a significant influence on runoff pollutant concentrations. The effects of AADT, total event rainfall, seasonal cumulative rainfall, antecedent dry period were statistically significant for nearly all of the constituents evaluated, and were very consistent across pollutant categories. Summarises data on: Relationships Between Runoff Quality and Other Factors, Event and Seasonal "First Flush" Effects, Comparisons of Runoff from Different Facility Types, Effect of Local Land Use on Runoff Quality, Effect of Geographic Regions on Runoff Quality, Trends and Annual Variability, comparison with WQ objectives, Correlations Between Constituents and Percentage of Metals in the Particulate Fraction.	The primary environmental factors affecting the quality of edge-of-pavement runoff have been identified and quantified, and major patterns of temporal variability (seasonal and intra-storm) have been characterized. The monitoring conducted to date has focused on runoff from paved surfaces. AADT is the most important site characteristic in predicting highway runoff quality. Although facility type, geographic region and contributing land use were determined to have some statistically significant effects on runoff quality, these effects are less consistent than AADT. Pollutant build-up and wash-off are evident in the statistical analysis of the highway runoff quality data, providing support for the concepts of seasonal and event first flush effects.	3
[31]	Higgins N. (2007) *Analysis of Highway Runoff in Ireland,* Trinity College. Department of Civil, Structural and Environmental Engineering, 2007, 443 pp.	Thesis	2007	EN	4 non-urban motorway sites monitored for flow and quality as well as storm event conditions. TSS seen as key pollutant but HMs,HCs (incl PAH), and nutrients, chlorides also covered.	Multiple regression analysis of flow and pollutant concentrations/loadings with storm event characteristics, Sediment, invertebrate and fish impact assessment of flow/surface water quality.	Yes	Yes for storm events sampled and impact studies.	All 4 motorway sites composed of hot rolled asphalt and installed in last 13 years carrying between 25-30,000 ADT. Rainfall volumes and intensity of recorded storm events relatively low varying between 462 - 711mm total and 0.8-43 mm for individual events for storm durations varying between 11 - 1295 minutes. Runoff coefficients were in region of 0.6 - 0.9 except for the filter drain site (Site C) where substantial by-passing of the drainage occurred with R-square values of 0.2. Impact assessment of storm event flows and quality on filter drain and a receiving wetland were investigated	Conventional storm event flow-weighted monitoring demonstrated that the nature, concentrations and loadings of pollutants were broadly similar with those Reported from similar conditions in other European countries particularly with equivalent non-urban highways in England. The kerb/gully piped system contributed quite high pollutant concentrations (although little MTBE found) to surface washoff with filter drain offering effective but short-term retention treatment. Water balance studies showed the filter drain to be subject to considerable bypassing. Primary positive regression analysis demonstrated between pollutant concentrations and rainfall intensity, ADP with secondary subsidiary relationships with traffic volumes and preceding storm conditions. Multiple linear regression predicted up to 90% of TSS variation as the key indicative contaminant.	Monitoring and modelling of some 200 individual storm events over a 15 month period at 4 non-motorway sites demonstrated clear relationships between storm event characteristics and pollutant concentrations and loadings. Rainfall intensity/volume and ADP appear to be the principal driving parameters with traffic volume and preceding conditions only showing weak correlation. HM concentrations declined in the order of Cd<Pb<Cu<Zn with HMs, TSS and PO4 frequently exceeding EU EQS and also exhibiting strong first flushes	4
[32]	Higgins N., Johnson P., Gill L, Bruen M., Desta M. (2008) *Highway Runoff in Irteland and Management with a French Drain System*. Proc.11th Int. Conf. Urban Drainage, Edinburgh, Scotland	Conference Proceeding	2008	EN	as above	as above	as above	as above	as above	as above	as above	4
[33]	Desta M., Bruen M., Higgins N. and Johnston P. (2007) *Highway Runoff Qualikty in Ireland,* Journal of Environmental Monitoring, 9(4), 366 - 371	Paper	2007	EN	as above	as above	as above	as above	as above	as above	as above	4
[34]	Bruen M., Johnston P., Quinn M., Desta M., Higgins N., Bradley C., Burns S. (2006) *Impact Assessment of Highway Drainage on Surface Water Quality,* Report 2000-MS-13-M2, Enviroment Protection Agency (EPA), Dublin, Ireland	Report	2006	EN	as above	as above	as above	as above	as above	as above	as above	4

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[35]	Moy F., Crabtree R. (2003) *Long Term Monitoring of Pollution from Highway Runoff,* M4. Brinkworth Brook: Site Report. Environment Agency, Bristol, UK	Report	2003	EN	2 year study. Data available on CD-ROM from HA/EA England. 10 storm events monitored with full rainfall listings at 5 - 15 minute intervals. 40 contaminantgs incl 12 HMs, 16 PAHs, 5 herbicides, TSS, Cl. BOD/COD and NH4.	Correlation graphs for storm event relationships; rainfall volume, runoff, intensity, duration, ADP and traffic volumes against individual pollutant conc and loadings	Yes. Biological kick sample surveys and sediment analysis	YES and available on CD-ROM	3-lane motorway site with hot rolled asphalt surface only 2 years old carrying high AADT > 70000 with 18% HGV. Required >3mm rainfall to initiate flow with storm event flow depths being typically 20-30mm for discharges of 3 - 5 l/s with maximum recorded discharge of 17.9 l/s. In summer considerable by-passing and infiltration of runoff in the conveying carrier ditch prior to discharge.	Full rainfall listings at 1 min. interval for 10 storm events over a 13 month monitoring period are Reported as well as upstream/ downstream in the receiving watercourse. Depth and flow velocity monitoring coupled to rainfall monitoring with further upstream/downstream monitoring of the receiving water to assess impact on aquatic biota. Analysis of discrete and composite sampling for 40 determinants with seasonal comparisons. Data used to identify averages and ranges of pollutant concentrations and loadings for differing storm event and site/traffic conditions. In addition, treatment efficiency and biological/ecological impact assessment investigated for the receiving watercourse.	BOD/COD tended to increase downstream during storm events with TSS concentrations varying between 3 - 12 mg/L. Sediment sampling showed elevated HMs and PAHs associated with the highway outfall but only low to moderate increases downstream. Many of the individual PAH species exceeded both DWS and EQS (MPV) standards. No statistical trends or relationships found between rainfall characteristics (or ADP) and pollutant concentrations/loadings although an apparent relationship existed for low rf. intensities and high flows during summer months.	4
[36]	Moy F., Crabtree R., Simms T. (2003) *Long Term Monitoring of Pollution from Highway Runoff,* Final Report. R&D Tech.Report Highways Agency/Environment Agency, Bristol, UK	Report	2003	EN	as above	as above	as above	as above	as above	as above	as above	4
[37]	Hewitt C.N., Rashed M.B. (1992) *Removal rates of selected pollutants in the runoff waters from a major rural highway*, Water Research, 26(3), 311-319	Paper	1992	EN	Monitoring of suspended solids, dissolved and particulate phases of Pb, Cd and Cu, dissolved total organic Pb and dissolved total PAHs (and 8 individual PAHs) concentrations in discharged highway runoff (13 storm events).	Derives a simple regression model which allows the reliable first-order approximation of Pb concentrations and removal rates in the runoff waters to be made from the discharge rate and the length of the ADP	No	Chemographs provided for 2 storms; mean ± SD and ranges provided for 13 storms for dissolved and particulate pollutants	Runoff waters sampled from a 1.6 km rural length of the M6 motorway in NW England (grid reference SD 528775). The motorway consists of two three-lane carriageways separated by a 2.0 m central reservation and bounded on each side by a 3.8 m paved hard shoulder. The section has a longitudinal slope of 1.3%, cross-sectional slopes of 2.5 and 3.3% for the carriageway and hard shoulder, respectively, an impervious drained area of 55170 m^2 and a permeable area of 30210 m^2. Schematic of sampling site and sample collection details provided. The period of study was 12 April 1986-11 April 1987; the daily average traffic flow was 32,000 petrol and 5600 diesel powered vehicles. A total of 13 different storms and seven periods of low flow were intensively sampled.	The concentrations of Cd, Cu, Pb, the organic compounds of Pb and PAHs were measured in surface drainage waters from a major rural highway in north-west England during a number of runoff events. The particulate phase (>0.45 µm) contained >90% of the inorganic Pb, ~70% of the Cu and ~ 56% of the Cd and the particulate-phase metal concentration profiles largely followed those of the suspended sediments. A "first-flush" effect was seen for the dissolved metals. A highly significant correlation was found between the length of the antecedent dry period and the amount of Pb and dissolved Cu removed during a runoff event but this was not found for the other pollutants. A simple regression model allows the reliable first-order approximation of Pb concentrations and removal rates in the runoff waters to be made from the discharge rate and the length of the ADP. Budget calculations show that ~8% of the Pb. 5% of the organic Pb and 3% of the PAHs emitted by vehicles are removed in the highway drainage waters.	The first-flush effect found to have a significant influence on the removal of metals in the road runoff waters. The behaviour of the particle-associated material and total PAHs closely follow that of the TSS. A simple regression model based on the length of the ADP and the rate of discharge is used to make accurate predictions of the rate of removal of Pb. The same good correlation between removal rate and length of the ADP was not found for the other pollutants. Although the obtained regression parameters are site specific the methodology described and the general form of the relationships between pollutant load, discharge rate and ADP should be applicable elsewhere and for other vehicle-derived pollutants. Budget calculations based on the estimated emission rate of the pollutants under highway driving conditions indicate that about 8, 5 and 3%, respectively, of the total Pb, organic Pb and total PAH emitted by vehicles on the 1.6 km stretch of motorway that drains into the sampled culvert are removed in the drainage waters. The differences in these percentages are attributed to differences in the physico-chemical characteristics of the pollutants.	3
[38]	Hares R.J., Ward N. (1999) *Comparison of the heavy metal content of motorway stormwater following discharge into wet biofiltration and dry detention ponds along the London Orbital-M25 motorway*, The Science of the Total Environment 235, 169-178	Paper	1999	EN	Two rural outfall discharges from the M25 are monitored for unfiltered concentrations of V, Cr, Mn, Co, Ni, Cu, Zn, Mo, Cd, Sb and Pb. The outlets from both wet biofiltration and dry pond treatment facilities are also monitored and the main purpose of the study is to assess the removal efficiencies of these treatment systems.	No modelling; Emphasis on treatment means relevant for WP3	No	Average metal concentrations over the sampling period (for both wet and dry conditions) Reported in the motorway discharges for both sites	Site 1: Drainage area covers two sides of a three-lane concrete roadway and a hard shoulder area; average daily traffic density is 140 000 vehicles per day. Site 2: Rainfall runoff from collected from a 2.24 km (76 160 m^2) stretch of carriageway (conventional asphalt surface) ; average traffic density of 120 000 vehicles per day. Samples collected (10 sampling visits) during dry weather conditions and during the initial stages of storm events between January 1997 and February 1998. A five day ADP existed before stormwater samples were collected. A total rainfall of 692 mm occurred over the sampling period.	The Surrey section of the London Orbital M25 motorway uses mainly detention pond facilities for the treatment of stormwater runoff. A majority of these implement the use of dry detention basins. However, in a few locations biofiltration facilities operate through the use of reed bed systems. An assessment of the removal efficiencies for both wet biofiltration and dry pond treatment facilities was undertaken. Motorway-derived contaminants, including V, Cr, Mn, Co, Ni, Cu, Zn, Mo, Cd, Sb and Pb, were measured in unfiltered stormwater collected during the initial stages of a storm event using inductively coupled plasma mass spectrometry _ICP-MS.. Results suggest that a higher level of motorway-derived heavy metal contamination exists in stormwater runoff from a road section with a higher average daily traffic density. In addition, a comparison of both sites shows a higher percentage removal efficiency of heavy metals in stormwater from the biofiltration facility.	Each balancing pond and treatment facility has unique processes that allow the removal of the heavy metals from stormwater. A biofiltration pond enables particulate material to settle out, through a reed bed pond with further sedimentation through a wet pond. A conventional oil interceptor, grit and silt traps, and a dry detention pond facility all aid heavy metal removal. The removal efficiencies of heavy metals within the biofiltration pond are higher than those from the corresponding dry detention pond facility. This result seems surprising due to the lack of specific pollutant removal devices (oil separator, grit trap etc.) and minimal maintenance within theisfacility. However, removal of particulate material through the attainment of a long residence time from motorway surface to receiving watercourse will predominate the heavy metal removal efficiency, especially as a majority of the motorway-derived heavy metals exist either as insoluble species or adhered to insoluble particulate material.	3
[39]	Crabtree B., Moy F., Whitehead M., Roe A. (2006) *Monitoring pollutants in highway runoff,* Water and Environment Journal, 20, 287-294	Paper	2006	EN	40 determinands monitored including 12 metals (totals + dissolved Cu and Zn), 16 PAHs, 5 herbicides, BOD, COD, hardness, Cl, TSS and ammonia.	No	No	Yes	Each of the 6 sites described in terms of highway/receiving water, 2 way AADT, road surface material, drainage area and percentage running traffic area. Full details of treatment facilities provided. Flow-weighted highway runoff samples collected for 10 wet weather events at each site.	Describes a 5 year study to collect data to improve the understanding of pollutants in highway runoff and the treatment efficiency of drainage systems. Non-urban highway drainage monitored at 6 sites each for a minimum of 1 year. Results used to identify rages of pollutant concentrations in highway runoff, relationships between runoff concentrations/loads and both highway and environmental factors, drainage system treatment efficiencies, and impacts on receiving waters. Results Reported as EMCs (mean and maximum) and loads (mean/1000 m2) for a total of 60 events (10 events at 6 sites). Removal efficiencies Reported for bypass oil separator, full retention oil separator, oil trap manhole, filter drain, sedimentation tank, dry balancing pond, wet balancing pond, wet balancing pond/surface flow wetland and treatment combinations.	The amount of available data limits the identification of relationships between event and site characteristics and the runoff quality at individual sites. Although pollutant concentrations in highway runoff are generally low, most determinants, and in particular metals , appear to be elevated following winter salting. A relationship may exist between runoff concentration and rainfall intensity. Results from the monitored treatment systems indicate that wet balancing ponds were the most efficient at removing the range of pollutants present in routine highway runoff. A more comprehensive dataset is required to support the development of an improved methodology to predict the concentrations of soluble and insoluble pollutants in highway runoff and the potential for any resulting impact.	5
[40]	Revitt D.M., Shutes R.B.E., Jones R.H., Forshaw M. (2004) *The performances of vegetative treatment systems for highway runoff during dry and wet conditions*, Science of The Total Environment, 334–335, 261-270	Paper	2004	EN	Monitoring of inlet and outlet concentrations to two different treatment systems receiving runoff from a non-urban highway (A34 Bypass, Newbury, Berks, UK). 5 storm events monitored and data made available in Database Matrix (Ref: MDX4). Pollutants monitored include BOD, suspended solids, Cd, Cr, Cu, Ni, Pb, Zn, nitrate and sulphate.	no	no	Data made available in Database Matrix (Ref: MDX12 data)	The A34 Newbury Bypass is a 13.5-km porous asphalt-surfaced dual carriageway which opened in November 1998. The drainage system includes a series of nine vegetated balancing ponds located adjacent to the highway. Each balancing pond incorporates a front –end oil interceptor and rectangular concrete sediment trap followed by a grassed slope to deliver the highway runoff to the treatment system. Two ponds have been monitored: Pond B exists as originally designed; Pond F/G was retrofitted to produce a subsurface flow-constructed wetland containing a gravel substrate preceded by a small settlement pond. Further details can be provided	The performances of two different highway runoff treatment systems, a horizontal subsurface flow-constructed wetland and a vegetated balancing pond, are described. Both systems have been assessed by collecting inlet and outlet grab samples during wet and dry weather conditions, and automatically controlled storm event samples have been obtained for the constructed wetland. Removal efficiencies are discussed for BOD (grab samples only), suspended solids, Cd, Cr, Cu, Ni, Pb, Zn, nitrate and sulphate, and explanations are offered for the trends observed under different weather conditions. The large removal efficiency ranges for five separate storm events, exhibited by Cu and Pb, are discussed and compared to the other monitored pollutants which showed positive median wet weather removal efficiencies of between 43% and 85%. Despite the existence of performance fluctuations, the generally low monitored inlet concentrations in the highway runoff indicated that the pond discharges did not threaten the environmental quality of the receiving waters.	The results presented in this Paper highlight the limitations of utilising analysed grab samples as the basis for estimating pollutant removal efficiencies between the inlet and outlet of a water treatment system, particularly in wet weather conditions. Comparison of the performance of a constructed wetland and a vegetated balancing pond receiving highway runoff pollutants shows only the constructed wetland showing a statistically significant removal efficiency greater than zero. Carefully planned storm event sampling can provide reliable removal efficiencies calculated from inlet and outlet loadings. Data obtained for the constructed wetland show evidence of increased or equivalent removal of several pollutants during storm events in comparison to dry weather conditions. Despite the variability in the pollutant removal efficiencies, particularly during dry conditions, the generally low inlet concentrations result in pond discharges, which do not threaten the environmental quality of the receiving waters.	2

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[41]	Legret M., Pagotto J. C. (1999) *Evaluation of pollutant loadings in the runoff waters from a major rural highway*, The Science of the Total Environment, 235, 143-150	Paper	1999	FR	Rural motorway runoff concentrations and loadings Reported for pH, conductivity, suspended solids, COD, total hydrocarbons, PAH, chlorides, sulphates, nitrates, ammonium, Pb, Cu, Cd and Zn.	Simple modelling only via mass balance calculation	No	Reported results are expressed as mean, medians, ranges and standard deviations for raw runoff waters and filtered runoff waters. Runoff loadings expressed in kg/km units	The monitored site is located on the north bypass motorway (A11) of Nantes Loire-Atlantique, France; the mean daily traffic flow rate is approximately 12 000 vehicles per day in both traffic directions including approximately 7% of heavy lorries. The pavement, at the time of the investigation, consisted of a. The motorway consisted of two three-lane carriageways (traditional asphalt surface) separated by a central reservation (11.65 m total width). Runoff water collected from the southern carriageway of a bridge representing a road length of 275 m and a contribution area of approximately 3200 m^2. The water was re-routed toward a measuring channel equipped with a V-shaped overflow and an immersed ultrasonic flow meter. Two flow weighted automatic samplers were used to take both mean and fractional samples. Sampling period (28 March 1995 to 26 February 1996) covered approximately 50 rain events from which 20 pollutographs were produced (total precipitation 656 mm and the effective fraction of this inducing runoff was of 608 mm). 90% of the rainfall events had a precipitation depth ranging between 2 and 20 mm.	The quality of surface runoff water from a 275-m motorway section has been studied for 1 year, during which approximately 50 rain events have been sampled. Two different types of pollution have been revealed. One type can be defined as chronic and includes suspended solids, chemical oxygen demand, total hydrocarbons, zinc and lead. The second type can be considered to be seasonal and incorporates chlorides, sulfates, suspended solids and heavy metals due to the use of de-icing salt in winter. Pollutant loading as regards lead appears lower than in previous studies because of the increasing number of vehicles using unleaded gasoline. The study conducted on the sources of pollution and on heavy metal fluxes Pb, Cu, Cd, Zn released by the traffic has been used to assess a mass balance with respect to pollutant loadings removed by runoff waters. It seems that a large proportion of the lead concentration may disperse in the atmosphere, whereas cadmium sources may be ill-identified or underestimated.	Motorway surface runoff water contains a large quantity of suspended solids, of chemical oxygen demand, of hydrocarbons and heavy metals. This pollution is increased during the period when de-icing salts are used. In comparison with data previously measured in France, lead pollution loads have decreased because of the marked drop in the use of leaded gasoline since 1993.	3
[42]	Aryala R.K., Furumai H., Nakajimab F., Boller M. (2005) *Dynamic behaviour of fractional suspended solids and particle bound polycyclic aromatic hydrocarbons in highway runoff*, Water Research, 39, 5126–5134	Paper	2005	CH	The dynamic washoff behavior of total SS, fractional SS and their particle associated PAHs is studied in first flush based on long-term runoff monitoring.	Consideration of relationships between TSS and SS during runoff conditions and also between associated PAHs.; but no direct relevance to Task 1.2	No	24 runoff samples were subjected to TSS, SS and PAH analysis; full data Reported for only 4 rainfall events with varying characteristics	Monitoring was conducted at an inlet point of treatment facilities for a highway drainage system with an area of 8.4 ha in Winterthur, Switzerland, from September to December 2000. Sampling site is at intersection of Highway A1 (1.8 km, 5.5 ha, ADT; 57,500) Highway A4 (1.2 km, 2.0 ha, ADT:25,300) and ramp area (0.6 km, 0.9 ha, ADT; 73,700). The sampler was programmed to collect the initial 3 mm runoff volume to focus on the first flush phenomenon. Full hydrological data provided for 4 runoff events.	A long-term continuous runoff monitoring was carried out in a highway in Winterthur, Switzerland. The total suspended solids (TSS) samples were fractionated into fine (<45 µm) and coarse (>45 µm) fraction and their washoff behaviour was studied. The fine and coarse fraction showed different washoff behaviours. During the runoff the concentration of the fine fraction was less fluctuated compared to coarse. The fluctuation of the coarse fraction was more influenced by TSS concentration. The PAH content measurement in fine fraction showed less fluctuation compared to the coarse fraction. The PAH content in the coarse fraction was found decreasing with increasing the coarse fraction contribution to TSS.	The particle size distributions of TSS in runoff samples showed that contribution of fine particles is higher to the TSS concentration than coarse fractions. The concentration of fine fractions (<45 µm) was found to be less dependent on rainfall characteristics as compared to coarse fractions (>45 µm). The fine fraction attained almost similar concentration (saturation state) after crossing certain TSS concentration while the coarse fraction showed power growth ($Y = mX^n$) with increasing TSS. PAHs concentration profiles in total as well as in SS fractions fluctuated with corresponding SS runoff behaviour. The high contribution of fine particles to TSS and their PAH enrichment suggested the importance of fine particles runoff behaviour in terms of pollutant loading.	2
[43]	Pagotto C. , Legret M., Le Cloirec P. (2000) Comparison of the hydraulic behaviour and the quality of highway runoff water according to the type of pavement, Water Research, 34(18), 4446-4454	Paper	2000	FR	This Paper updates the work described in [33] in that the same highway site is monitored but after the original surface had been replaced by porous asphalt. The results are compared with those previously obtained for a conventional asphalt surface.	No	No	Yes [41] for details of monitored pollutants which in this Paper are compared for porous asphalt with the previous conventional asphalt surface.	See [41]	This Paper presents the results of an experimental investigation aimed at determining the impact of the type of pavement, whether conventional or porous, on the hydraulic behaviour and on the quality of runoff water. Data obtained from a French highway both before and after the replacement of a conventional asphalt by a porous asphalt are compared. Statistical tests have been used to evaluate the significance of the differences detected. Firstly, the differences in hydrological behaviour between the two types of pavement are highlighted (retardant effect on the evacuation of water into the outlet, peak flow attenuation, mitigation of splashing by the pervious pavement). Secondly, the impact on water quality is investigated. The retention of particulate pollution by the porous pavement, which acts as a filter, is clearly demonstrated. This study also shows the probable impact of the type of pavement on the pollutant content in a dissolved form.	This study has underlined the main effects of a porous pavement, in comparison with conventional asphalt. Concerning hydrological behaviour, a porous asphalt allows a gradual evacuation of water into the outlet (peak flows are limited and times of discharge are longer). Splashing is reduced as well as wind dispersion and evaporation. Runoff water quality is improved, for the main pollutants of runoff water: heavy metal loads discharged into the environment are reduced from 20% (Cu) up to 74% (Pb); solids are detained at a rate of 87% and hydrocarbons are intercepted at an even higher rate (90%). The retention of fine particulate pollution (not subject to settling) by porous pavement filtration explains the reduction in the amount of hydrocarbons and metals. Other mechanisms however can also be at work, namely the retention of coarse particulate pollution by filtration and the retention of certain dissolved forms of metals, such as Zn and Cd (adsorption).	3
[44]	Roger S., Montrejaud-Vignoles M., Andral M., Herremans L., Fortune J.P. (1998) *Mineral, physical and chemical analysis of the solid matter carried by motorway runoff water,* Water Research, 32(4), 1119-1125	Paper	1998	FR	Main analytical work Reported is for sediments deposited in collection channel after each of 9 rainfall events. Runoff samples also collected and divided into soluble fraction (particle sizes less than 0.8 µm) and a solid fraction corresponding to the total suspended solids (TSS); but only for 2 events. TSS subjected to determination of % of weight and % of organic matter, specific mass and metal content for Al, Zn, Pb, Cu, Ni, Cr, Cd.	No	No	The emphasis is on the sediments deposited in the collection channel with only very limited data provided for the separated suspended sediments in the runoff waters.	Highway surface area of 13 000 m^2 with a length of 300 m and width of 30 m (2x3 lanes). The average ADT is 30 000 vehicles per day and the average vehicle speed is 110 km/h. The runoff water and the sediment deposited in the collection channel were collected after 2 and 7 periods of rainfall, respectively between 28 October 1993 and 04 February 1994.	A physical and chemical study of the runoff water from a motorway catchment area in the Herault region. The distribution of particle sizes and the physical, chemical and mineral characteristics of the sediment contained in the runoff water were analysed for rainfall occurring between February 1993 and March 1994. On average, 90% of the solid matter by weight was in the form of particles smaller than 100 µm. The main organic and metallic constituents of motorway traffic pollution were contained in this sediment. The analysis of the sediment carried by the runoff showed that it contained mineral and organic matter. The contents of this matter were further analysed using X-ray diffraction, thermogravimetry and specific mass measurement. Particles smaller than 50 µm were composed of clays (56%), quartz (15%), chalk (12%), organic matter (9%), feldspars (5%) and dolomite (2%). The specific mass of the particles decreased with the size of the particles and, simultaneously, the percentage of organic matter increased. Excessive Pb and Zn contamination was found in both the organic matter and the clay, which formed the largest fraction of particles smaller than 50 µm.	The main organic and metallic pollution in the runoff water from a section of the A9 motorway was contained in the smaller particle range sizes: an average of 90% of the solid matter by weight was made up of particles smaller than 100 µm and 78% was made up of particles smaller than 50 µm. The clays which represent 56% of the fraction of the suspended solids analysed are especially interesting for the retention of the metallic micropollutants, because the mineral analysis showed that the montmorillonite of the smectite family formed part of the clay fraction. This mineral has a high cationic exchange capability, which makes it particularly able to trap certain organic molecules. This was confirmed by a high correlation between Zn, the clays and the organic matter. The analysis of the sediment from the runoff showed that it was composed of mineral and organic matter. As the specific mass decreased so did the particle size and organic matter content. The percentage of organic matter is smaller than the percentage obtained in other studies, between 18% (urban highway with low vehicle speed) and 33% (combined sewer overflows). This difference arises from the configuration of the studied site: a high speed highway producing fewer organic deposits and without urban wastewater.	1
[45]	Gan H., Zhuo M., Li D., Zhou Y. (2007) *Quality characterisation and impact assessment of highway runoff in urban and rural area of Guangzhou, China*, Environmental Monitoring and Assessment, 140, 147-159	Paper	2007	China	Monitoring of 7 storm events at a rural highway for the following pollutants: oil & grease, COD, BOD, TOC, SS, TN, TP, OP, nitrate, Cu, Zn, Pb, Cd, Ni and Cr.	Regression modelling described for runoff quality against hydrological characteristics (rainfall depth, mean rainfall intensity and ADP).	No	EMC data provided for 7 storms at a rural site together with full hydrological data.	The rural highway consists of two 3 lane carriageways separated by a central green belt. The monitored drainage area (110 m^2) is part of the southbound lane with a transverse slope of 0.02 m/m. Runoff water is collected by a drop inlet. ADT = 31,000 with 60% heavy lorries. The surrounding land is composed of vegetable fields.	The quality characterisation and environmental impact assessment of rainfall runoff from highways in urban and rural areas of Guangzhou are presented for a 1 year investigation. Oil & grease, SS and heavy metals are the dominant pollutants in contrast to the low levels of nutrients in runoff. Highway runoff quality at the rural site is better than that at the urban site for most constituents. Rainfall depth and ADP are the main factors influencing the quality of highway runoff.	The runoff water from highways is nearly neutral with low biodegradability. O&G, SS and heavy metals are the dominant pollutants. The concentrations of most contaminants exceed data Reported from developed countries. EMCs of constituents at the urban site are 6-73% higher than at the rural site except for pH, TOC and OP. Rainfall depth and ADP can explain approximately 30-70% of the variation in the EMCs except for TOC, SS, TP and Cr. The surface soil layers adjacent to the discharge from the rural site have been contaminated by heavy metals (down to 40 cm depth).	4

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[46]	Huber M., Welker A., Helmreich B. (2016) *Critical review of heavy metal pollution of traffic area runoff: Occurrence, influencing factors, and partitioning*. Science of the Total Environment, 541, 895–919	Paper	2016	EN	Includes an analysis of a dataset of 294 monitored sites from six continents (Africa, Asia, Australia, Europe, North and South America). Sites divided into eight traffic area categories (parking lots, bridges, and three types each of both roads and highways). Highways categorised as urban HWY with an AADT of >30,000 (HU); non-urban HWY with an AADT of >30,000 (HN); and HWY with an AADT of <30,000 (HL). Unfortunately highway sites are not identified and details are not tabulated.	Refers to best correlating factors for the prediction of heavy metal runoff quality	No	Statistical analysis provided for dissolved and total heavy metal concentrations obtained from 33 non-urban highway sites.	No details provided for any of the 33 non-urban highway sites.	A dataset of 294 monitored sites from six continents (Africa, Asia, Australia, Europe, North and South America) was compiled and evaluated to characterize the occurrence and fate of heavy metals in eight traffic area categories (parking lots, bridges, and three types each of both roads and highways). In addition, site-specific (fixed and climatic) and method-specific (related to sample collection, preparation, and analysis) factors that influence the results of the studies are summarized. These factors should be considered in site descriptions, conducting monitoring programs, and implementing a database for further research. Historical trends for Pb show a sharp decrease during recent decades, and the median total Pb concentrations of the 21st century for North America and Europe are approximately 15 µg/L. No historical trend is detected for Zn. Zn concentrations are very variable in traffic area runoff compared with other heavy metals because of its presence in galvanized structures and crumbs of car tire rubber. Roads with more than 5000 vehicles per day are often more polluted than highways because of other site-specific factors such as traffic signals. Four relevant heavy metals (Zn, Cu, Ni, and Cd) can occur in the dissolved phase. Knowledge of metal partitioning is important to optimize stormwater treatment strategies and prevent toxic effects to organisms in receiving waters.	Heavy metal pollutant loads determined at a given site depend on the unique subset of site-specific (surrounding land use characteristics, traffic area site data, operational characteristics, and climatic factors) and method-specific factors (sample collection, preparation, analysis, and calculation). From the literature, inconsistent conclusions have been obtained regarding how specific variables affect traffic area runoff. Thus, a combination of several interacting factors results in heavy metal runoff pollution, and these factors should be described in detail for each monitoring site. These factors should also be implemented in databases to allow further specifications in future. Roads with more than 5000 vehicles per day are often more polluted than HWY because of other site-specific factors such as braking and acceleration at traffic signals. Worldwide HWY runoff concentrations are not significantly influenced by AADT and urban/non-urban land uses. Pb and Cr are mostly particle-bound, while Zn, Cu, Ni, and Cd occur at a higher fraction in the dissolved phase. Therefore, the treatment of runoff waters containing dissolved heavy metal pollutants by stormwater treatment strategies is important. Further traffic-related elements are Mn, Rh, Pd, Pt, and Ti. As tracers, Co, W, and Sb, which have anthropogenic sources, are potentially suitable for traffic areas. Reported mean concentrations (µg/L) are 31.7±35.8 (for Pb), 385±193 (for Zn), 29.3±23.7 (for Ni), 84.4±39.1 (for Cu), 2.6±1.4 (for Cd) and 25.0±23.9 (for Cr).	2
[47]	Opher T., Friedler E. (2010) *Factors affecting highway runoff quality*, Urban Water Journal, 7(3), 155-172	Paper	2010	EN	Review Paper covering heavy metals, PAHs, VOCs, MTBE, herbicides. SS in highway runoff.	Reviews the factors which have been proposed as predictors for the quality of highway runoff. Deduces that there are no simple relationships and that individual event EMCs are a result of a combination of traffic density and a number of interacting variables related to rainfall event and highway site characteristics.	No	Tabulated data is provided for EMCs in highway runoff from 6 previously conducted studies in the USA (4), UK (1) and Israel (1)	Not relevant	This review describes the main pollutants (heavy metals, refractory organics, suspended matter) and analyses the interactions which exist between them as well as their fractionation between the particulate and dissolved phases. The main factors influencing highway runoff quality are Reported to be traffic (AADT, VDS [vehicles during a storm], ATC [single lane vehicle count], ADP, storm characteristics (rainfall/runoff volume, rainfall intensity, storm duration), previous storm characteristics, climatic factors, land use and other factors (type and condition of road surface, road sweeping, highway site situation and time elapsed since beginning of an event).	Some sources of highway runoff are constant while others are nearly impossible to measure or estimate. Numerous factors depicting storm characteristics, road situations, ambient conditions and environmental attributes are assumed to have simultaneous and sometimes contradicting influences on the extent of pollutant presence in highway runoff. Hence the cause and effect relationships with regard to pollutants in highway runoff are complicated and often inconclusive. Even among obvious influencing factors such as daily traffic, there are contradicting findings from different studies. These arise as a consequence of significant variance in pollutant concentrations among study sites and within each site, between different runoff events, or to additional effects which have not been taken into account. Statistical methodologies, data-driven modelling or other machine-learning techniques may be able to overcome the difficulties of dealing with numerous variables and vast variability.	4
[48]	Hurle R., Bury N., Caswell B ., Bark T ., Mustow S., Nottingham I ., Whitehouse P., Whitehead M. (2005) *The impact of soluble pollutants in highway and urban runoff on the ecology of receiving waters*. Proc. 3rd CIWEM National Conference. Wakefield. Yorkshire. UK	Conference Proceeding	2005	EN	as above	as above	as above	as above	as above	as above	as above	3
[49]	Crabtree B., Moy F., Whitehead M., Roe A. (2006) *Monitoring pollutants in highway runoff*. Water and Environment Journal, 20(4), 287-294	Paper	2006	EN	Summary of studies presented above	as above	as above	yes	as above	Highway surface runoff discharges may contain pollutants that have accumulated on the carriageway, particularly following periods of dry weather. The Highways Agency, in association with the Environment Agency, commissioned a 5-year study in 1997 to collect data to improve the understanding of pollutants in highway runoff and the treatment efficiency of drainage systems. The study involved the monitoring of nonurban highway drainage at six sites, each for a minimum of 1 year.	as above The results have been used to identify ranges of pollutant concentrations in highway runoff, relationships between runoff concentrations/loads and both highway and environmental factors, drainage system treatment efficiencies, and impacts on receiving waters. This Paper describes the methods used for runoff monitoring, the results obtained to characterise pollutants in highway runoff, and the measured pollutant removal efficiency of a number of drainage system types.	3
[50]	Crabtree B., Dempsey P., Johnson I., Whitehead M. (2007) *The development of a risk based approach to managing the ecological impact of pollutants in highway runoff*. Proc. 11th Int. Conf. Diffuse Pollution. 08/2007. Belo Horizonte, Brazil. IWA Publishing.	Conference Proceeding	2007	EN	Summary of studies presented above	as above	as above	as above	as above	as above	as above	3
[51]	Crabtree B., Dempsey P., Johnson I., Whitehead M. (2008) *The development of a risk assessment approach to manage pollution from highway runoff*. Proc 11th Int. Conf. Urban Drainage. Edinburgh. Scotland UK, IWA Publishing	Conference Proceeding	2008	EN	Summary of studies presented above	as above	as above	as above	as above	as above	as above	3

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[52]	Mayer T., Rochfort Q., Marsalek J., Parrott J., Servos M., Baker M., McInnis R., Jurkovic A., Scott, I. (2011) *Environmental characterization of surface runoff from three highway sites in Southern Ontario, Canada: 1. Chemistry,* Water Quality Research Journal of Canada, 46(2), 110-120	Paper	2011	EN	Monitoring study of road drainage from heavily trafficked highway bridge deck outside Burlington Ontario, Canada. Principal pollutant studied was chlorides from de-icers, but also included TSS, HMs and PAHs Highest concentrations and loadings associated with TSS and soluble fractions of runoff..	Major modelling effort for runoff quality and toxicity prediction based on artificial neural network (ANN) analysis and multiple regression. Of interest to Task 1.2	YES. Study also considers toxic impacts upon receiving water quality of highway runoff.	YES-some data analysis attached but further information available from references.	Study of multi-lane asphalt highway on road bridge deck outside Burlington, Ontario, Canada. High AADT densities with high proportion of HGV with 14 events sampled. Traffic intensity, seasonal conditions and road condition suggested as major influencing factors on chemistry and toxicity	Study focusses on a small drainage area of the extra-urban highway located at the James N Allen Skyway Bridge outside Burlington, Ontario, Canada. The 3-lane bridge is heavily trafficked and highway discharges were monitored over a 24 months period with the principal effort focussed on runoff chloride concentrations associated with winter de-icing operations. The modelling study also targeted identified runoff toxicity tests to investigate the probable vulnerability of the receiving watercourse in terms of predicted toxic impacts. A salt application optimisation tool was developed which predicts chloride concentrations in seasonal runoff discharges and artificial neural network (ANN) analysis predicts runoff concentration statistical distribution parameters for HMs, TSS and PAH EMC values. The study also investigated the efficiency of pollutant retention for a range of novel treatment media for roadside ditch drainage including blast furnace slag and woodships for control of HMs. Finally, differing liner types for roadside ditching were tested experimentally in field-scale pilot studies for a number of rainfall events.	Development and application of simple predictive snowmelt model based on temperature index (TI) approach to prevailing weather conditions and salt application loadings. Novel artificial neural network (ANN) analysis also used to incorporate rainfall volumes/intensity, AADT, ADP in order to predict seasonal runoff and pollutant loadings. Runoff solids found contained highest PAH levels (19 - 2142 mg/kg) and winter chlorides peaking at 19135 mg/L. Traffic intensity, highway condition and age as well as seasonal conditions. Companion Paper focusses on toxicity assessment of receiving water course impacts and vulnerability.	4,00
[53]	Trenouth, W. (2017) *Highway stormwater runoff quality: Investigation of improved operational, predictive and treatment approaches,* Unpuiblished PhD thesis, University of Guelph, Guelph, Canada	Thesis	2017	EN	as above	as above	as above	as above	as above	as above	as above	4
[54]	Trenouth W., Gharabaghi B., Perera N. (2015) *Road salt application planning tool for winter de-icing operations,* Journal of Hydrology, 524, 401-410	Paper	2015	EN	as above	as above	as above	as above	as above	as above	as above	4
[55]	Mayer T., Rochfort Q., Marsalek J., Servos M., Jurkovic A., McInnis R. (1998) *Effect of deicing salts on the chemistry and toxicity of highway runoff.* Tech.Note AEP-TN98-005. Nat.Water Res. Inst., Environment Canada.	Report	1998	EN	as above	as above	as above	as above	as above	as above	as above	4
[56]	R&D Technical Report P2-038/TR3. A417. *River Frome-Site Report*. ISBN 1844322106. October 2003. Environment Agency, Swindon, Wiltshire, UK	Report	2003	EN	2 year study. Data available on CD-ROM from HA/EA England. 10 storm events monitored with full rainfall listings at 5 - 15 minute intervals. 40 contaminants incl 12 HMs, 16 PAHs, 5 herbicides, TSS, Cl. BOD/COD and NH4.	Correlation graphs for storm event relationships; rainfall volume, runoff, intensity, duration, ADP and traffic volumes against individual pollutant conc and loadings	YES. Biological kick sample surveys and sediment analysis	YES and available on CD-ROM	5 monitored non-urban highway sites in SE England (all more than 5 years old) composed of asphalt/porous asphalt and heavily trafficked (>15000 ADT) with 14% - 18% HGV. All drained to some form of treatment facility prior to discharge to the receiving watercourse. Continuous flow monitoring of discharge and water quality and also upstream and downstream of the highway outfall. !0 wet weather events were recorded at each site although all events were relatively small scale in terms of volume and intensity. Biological surveys undertaken in the receiving water sites together with sediment samples for a total of 40 pollutants.	Depth and flow velocity monitoring coupled to rainfall monitoring with further upstream/downstream monitoring of the receiving water to assess impact on aquatic biota. Analysis of discrete and composite sampling for 40 determinants with seasonal comparisons. Data used to identify averages and ranges of pollutant concentrations and loadings for differing storm event and site/traffic conditions. In addition, treatment efficiency and biological/ecological impact assessment investigated for the receiving watercourse.	Full rainfall listings at 1 minute intervals for 10 storm events over a 13 month monitoring period are Reported as well as upstream/downstream in the receiving watercourse. BOD/COD tended to increase downstream during storm events with TSS concentrations varying between 3 - 12 mg/L. Sediment sampling showed elevated HMs and PAHs associated with the highway outfall but only low to moderate increases downstream. Many of the individual PAH species exceeded both DWS and EQS (MPV) standards. No statistical trends or relationships found between rainfall characteristics (or ADP) and pollutant concentrations/loadings although an apparent relationship existed for low rf. intensities and high flows during summer months.	4
[57]	R&D Technical Report P2-038/TR4. *M4. River Ray-Site Report*. ISBN 1844322114. October 2003. Environment Agency, Swindon, Wiltshire, UK	Report	2003	EN	as above	as above	as above	as above	as above	as above	as above	4
[58]	R&D Technical Report P2-038/TR5. *M40. Souldern Brook-Site Report*. October 2003. ISBN 1844322122. Environment Agency, Swindon, Wiltshire, UK.	Report	2003	EN	as above	as above	as above	as above	as above	as above	as above	4
[59]	R&D Technical Report P2-038/TR6. *A34 Gallos Brook-Site Report*. October 2003. ISBN 1844322130. Environment Agency, Swindon, Wiltshire. UK	Report	2003	EN	as above	as above	as above	as above	as above	as above	as above	4
[60]	R&D Technical Report P2-038/TR7. *A34 Newbury By-Pass-Site Report*. October 2003. ISBN 1844322149. Environment Agency Swindon, Wiltyshire. UK.	Report	2003	EN	as above	as above	as above	as above	as above	as above	as above	4

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[61]	24 WRC site Reports	Report	2003	EN								4
[62]	Vollertsen J, Åstebøl SO, Coward J., Fageraas T., Nielsen A., Hvitved-Jacobsen T. (2009) *Performance and Modeling of a Highway Wet Detention Pond Designed for Cold Climate*. Water Quality Research Journal of Canada, 44(3), 253–262	Paper	2009	EN	Monitoring of one highway pond in Oslo, Norway	No	No	Yes	One full year of highway runoff measurement (inlet to a pond)	A wet detention pond in Norway has been monitored for 12 months. The pond receives runoff from a highway with a traffic load of 42,000 average daily traffic. Hydraulic conditions in terms of inflow, outflow, and pond water level were recorded every minute. Water quality was monitored by volume proportional inlet and outlet samples. During most of the year, excellent pollutant removal was achieved; however, during two snowmelt events the pollutant removal was poor or even negative. The two snowmelt events accounted for one third of the annual water load and for a substantial part of the annual pollutant discharge. The performance of the pond was analysed using a dynamic model and pollutant removal was simulated by first-order kinetics. Good agreement between measurement and simulation could be achieved only when choosing different first-order rate constants for different parts of the year. However, no relation between the rate constants obtained and the time of year could be identified, and neither did the rate constants for different pollutants correlate. The study indicates that even detailed measurements of pollutant input and output allow only average performance to be simulated and are insufficient for simulating event-based variability in pond performance.	The detention pond exhibited very good overall pollutant removal, although snowmelts constituted a major challenge for the performance of the pond. These events caused significant pollutant discharges and the major part of the annual pollutant emission for a number of pollutants. Snow from highway shoulders frequently contains high concentrations of pollutants, which are discharged to a pond that is often ice-covered. The runoff water must therefore either pass over the ice sheet or under it, resulting in reduced pollutant removal and a risk of resuspension of bottom sediments. It gives matter for thought that the detailed and comprehensive monitoring of the Skullerud wet detention pond – performed at great expenses – does not yield results with a high reproducibility and correlation between pollutants. Model simulations showed that a combination of a high variability in the pollutant removal processes and a high variability in the association of pollutants to different fractions of particles and colloids are the main reasons for that. On this background it is concluded that input/output measurements on wet detention ponds can only be applied to allow the prediction of long-term pollutant removal, whereas the short-term behaviour calls for monitoring of the individual removal processes taking place in the pond.	3
[63]	Vollertsen J., Åstebøl S., Coward J., Fageraas T., Madsen H., Nielsen A., Hvitved-Jacobsen T. (2007) *Monitoring and modeling the performance of a wet pond for treatment of highway runoff in cold climates*. In: Highway and Urban Environment. Book Series: Alliance for Global Sustainability Series, 12, 499-509, ISBN 978-1-4020-6009-0	Paper	2007	EN	Monitoring of one highway pond in Oslo, Norway	No	No	Yes	One full year of highway runoff measurement (inlet to a pond) (same campaign and pond as the one above)	A wet pond in Oslo, Norway, receiving highway runoff was studied. The pond was equipped for continuous monitoring of inflow and outflow. Samples were collected over a 1-year period and analysed. The treatment performance was documented and an adverse effect of snowmelt runoff observed. The wet pond was modelled by routing the measured flow through the pond and simulating pollutant removal by 1st order kinetics. The relative importance of the permanent pool of water and the design storm storage was assessed with respect to pollutant removal. High pollutant reduction efficiency of a wet pond treating highway runoff under cold climate conditions is documented based on the results from a 1-year monitoring period. Furthermore and in general, wet ponds can be recommended as a technology for treatment of highway runoff also under such conditions. However, snowmelt can be a major challenge – partly because wet ponds become ice-covered and partly because adjacent hillsides may contribute to the runoff during winter.	In general, careful consideration must be given to winter-operation of wet ponds where these are placed in cold regions with significant snowfall. The volume of the permanent pool is shown to play the by far most important role in pollutant reduction, whereas the design storm storage volume is of minor consequence. When pollution reduction is the main issue and reduction of peak flow is not required, it is recommended to increase the size of the permanent pool on the expense of the design storm storage. Modelling the performance of a wet pond with 1st order kinetics yields a reasonable estimate of pollutant removal and allows dynamic simulation of real rainfall events. The approach is recommended as a design tool, applying long rainfall series together with empirical knowledge on removal rates to optimize the sizes of the permanent pool and the design storm storage.	3
[64]	Blecken G., Al-Rubaei A., Viklander M., Marsalek J. (2017) *25 municipal stormwater management ponds in Sweden – survey of the operational status (25 kommunala dagvattendammar i Sverige – hur fungerar de?),* Svenskt Vatten Utveckling (SVU), Report 2017-18	Report	2017	SE	Monitoring of stormwater pond sediment concentrations (metals)	No	No	Yes		During the past 50 years, wet stormwater ponds have been constructed to reduce negative environmental impacts of urban stormwater discharges on receiving aquatic environments. However, in many jurisdictions, there is little information on the current operational status of such ponds and their functioning. This paucity of information prompted a field survey of 25 Swedish municipal stormwater ponds aged between 3 and 26 years. The pond survey focused on estimating the pond hydraulic loading and efficiency, the state of littoral vegetation, characteristics of bottom sediment in the inlet and outlet zones (sizes and the chemistry), and the overall operational pond status, including the access for maintenance. The hydraulic efficiencies of ponds were estimated for pond footprint shapes and relative locations of the inlets and outlets, using literature data. The estimated hydraulic efficiencies correlated well with the pond length-to-width ratios and the ratio of the pond surface area to the impervious area of the runoff contributing catchment (i.e., the hydraulic loading). Littoral vegetation was inspected visually and found to be overgrown at some facilities, which impeded the maintenance access.	Benthic sediments in ponds contained silt and clay, sand and gravel fractions, and when compared to the literature data, such sediments appeared relatively coarse. Chemical characteristics of sediments reflected anthropogenic (traffic) activities, but without excessive contamination warranting special disposal requirements. Of the 25 ponds surveyed, four were fenced off and inaccessible to machinery. In fact the design of these four ponds was such that it made inspection and maintenance very difficult, which may pose potential risks to ponds operation. Fifty-four percent of the investigated ponds were in need of minor maintenance, mainly due to sediment and litter accumulation in their inflow and outflow sections. The fact that the inspection survey revealed relatively few minor issues that could be easily corrected demonstrates the importance of relatively simple regular inspections serving to detect minor problems at an early stage, before they would seriously impact on pond functioning. The above survey methodology should be helpful for developing similar low-cost surveys in other jurisdictions.	3
[65]	Bentzen, T. (2008) *Accumulation of pollutants in highway detention ponds*, Aalborg University Department of Civil Engineering, pp 60, ISSN 1901-7294,DCE Thesis No. 13	Thesis	2008	EN	Monitoring of stormwater pond sediment concentrations (metals and PAH)	No	No	Yes	Not present	This study deals with issues related to water and pollutant transport from highway surfaces caused by rain. The study applies methods and models in which improvements in relation to removal of pollutants can be identified and to be able to predict the yearly discharges of heavy metals and polycyclic aromatic hydrocarbons from an arbitrary detention pond to the natural environment. One of the main problems in prediction of pollutant load from road runoff is that the temporal varying intensity of the rain causes high variation of the runoff. Hence it is impossible from few measurements to predict annual pollutant loads from the runoff. The method that has been shown to be the most effective for coping with the time variation in the rain is a so-called hindcast where several years of measured rain are used for simulating the exact variation in runoff from every single rain event. From the hindcast results it is possible to calculate mean water and pollutant loads. The challenge was to develop a simplified and still accurate description of flow and transport of pollutant adequate for the long-term simulation of the pollutant transport from highways caused by rain. Because of the strong non linearity in the processes involved it is obvious that methods based on simple average concentrations cannot be applied when it comes to removal of particles in ponds.	Measurements of water and pollutant transport were carried out in different highway systems. A geometrically well-defined test pond was established, wherein the deposition of particulate matter was measured. The result from the test pond was transferred to real detention ponds in which the three-dimensional flow was described with a numerical CFD model. The particulate matter was analysed for grain size distributions, settling velocity distributions and corresponding heavy metal and PAH concentration. Erosion/resuspension experiments for detention pond sediments are carried out in the laboratory with currents and waves. In general the study showed that the bulk of hydrocarbons, PAH's and heavy metals accumulate in detention pond sediments and the removal efficiency for particulate matter in the detention ponds was around 80%. An important parameter for retention of particulate matter in Denmark is the wind - in that way, the calm water expedites the settling process contrary to turbulent water. The impact from the wind can reduce the pollutant removal efficiency significantly and even result in negative efficiencies due to resuspension of already settled particulate matter.	3

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[66]	Marianne Grauert, Michael Larsen, Mikkel Mollerup (2011). *Sedimentanalyser fra 70 regnvandsbassiner.* Rapport 191-2011, Vejteknisk Institut, Vejdirektoratet	Report	2011	DK	Monitoring of stormwater pond sediment concentrations (metals, carbohydrates and PAH)	No	No	Yes	Not present	As the Danish Road Directorate wishes to be at the forefront of knowledge of the impact of roads on the surrounding environment, it is necessary to know the extent of pollution produced on the roads and subsequently collected in stormwater ponds. This Report examines the chemical state of the sediments in the stormwater ponds, in order to be able to take more qualified environmental decisions in the future on the construction and operation of the ponds. The Road Engineering Institute has sampled sediments from 70 stormwater ponds, distributed throughout the Danish state roads. The sediment analyses show the extent to which wear on the surface of the road and of the cars, loss of fuel components and the like leads to pollution of the environment near the roads. This happens when the road runoff is discharged through stormwater ponds to lakes and streams.	Pollution is not heavy, but hydrocarbons are present in large quantities. The samples from the sediments from the ponds are analysed for hydrocarbons, PAHs, heavy metals and road salts, and the results show that 90% of the ponds have sediments that are at least slightly polluted and 61% have sediments that are significantly contaminated. It is the content of hydrocarbons that is particularly high and the number of polluted ponds can be reduced to 20% if the hydrocarbon content were to be reduced to values under the Environmental Protection Agency's cut-off criteria for contaminated soil. If the hydrocarbons can be reduced, this will mean a significant improvement in the state of the environment in the basins and the possibility of recycling the sediment will be improved. The content of PAH and heavy metals in the sediments is not high. In addition, the content is compared to 38 analyses from natural Danish lakes and the results show that there is no clear difference between the measured levels in stormwater ponds and natural lakes, but for copper that seems to be slightly elevated in stormwater ponds. Statistical surveys of the data set have shown that a large number of factors influence the distribution of concentrations in and between the ponds. Therefore, it has not been possible to find statistically significant correlations between the measured parameters..	3
[67]	Grung M., Vikan H., Hertel-Aas T., Meland S., Thomas K., Ranneklev S. (2017) *Roads and motorized transport as major sources of priority substances? A data register study*, Journal of toxicology and environmental health - Part A, 80(16-18), 1031-1047	Paper	2017	EN	Yes	No	No	No	Not present	A data register study was performed in order to identify the amounts of hazardous substances in products related to motorized transport in Norway during 2012. The hazardous substances were selected from legislative investigations performed by the European Chemicals Agency (ECHA), European Union (EU), and Norwegian Environment Agency (NEA). Information regarding hazardous substances in 52 selected product categories associated with traffic-related activities was obtained from the Norwegian Product Register administrated by the NEA. Substances present on ECHA list of substances of very high concern (SVHC), NEA national priority list, and priority substances under the EU Water Framework Directive (WFD) were given most attention, with substances from ECHA community rolling action plan (CoRAP) also included. Results showed that selected products contained a diverse range of substances that were classified as hazardous to either human or environmental health. The quantities of hazardous substances in the selected products were 120 tons (SVHC), 280 tons (Norway priority list), and 2,400 tons (WFD). It proved difficult to pinpoint these quantities only to traffic-related operations since product categories included compounds used for other activities. However, data illustrate that large quantities of hazardous substances are employed concurrent with being prioritized for reduction/elimination by national and international authorities. A list of substances with annual use in 2012 >1 ton was prepared to aid a prioritization for further actions such as substitution, phasing out, or environmental monitoring. The list contains substances that are toxic to humans, especially as adverse reproductive/carcinogenic agents, and/or pose a threat to the environment.	Many products related to motorized transport and roads contain substances that per legislation need to be phased out/reduced after 2015. The substances comprise hazardous substances that are regulated due to risks posed either to human health and/or to the environment. Many of the compounds are used in large quantities and in consumer products. With this background, we have prioritized a range of substances or further action, including regulative purposes and environmental monitoring. The 10 most important prioritized compounds were MTBE, benzene, tetrachloroethylene, hydrazine, medium-chain paraffins, tetraborates, NP and its ethoxylates, D5, and Orange lead. Several of the mentioned substances are prioritized by more than one authority (i.e. ECHA, NEA, WFD). It proved difficult to pinpoint the amounts directly to traffic-related operations as the selected product categories were diverse and included products employed in other areas such as civil engineering, shipping, and various industries. The results illustrate, however, that large volumes of hazardous substances are being used even if they are prioritized for reduction/elimination by the authorities. It is conceivable that our case study demonstrates the usefulness of the chosen approach and that a broader use of register data will advance less risk to human and environmental health in the future.	2
[68]	Ranneklev S. (2016) *Et litteraturstudium over forurenset snø fra bynære områder: stoffer, kilder, effekter og håndtering,* NIVA Report 27 p.	Report	2016	NO	Litterature study on snow	No	No	No	Not present	A literature study was conducted to acquire an overview of concentrations of organic environmental pollutants and metals in urban snow. Literature related to road salt was also included, in addition to literature on effects in biota exposed to urban snow during snow melting events and challenges and solutions regarding handling of snow in urban areas.	Results showed that levels of metals and organic contaminants were high, and exceeding the environmental quality standards in the EU WFD. Elevated concentrations of Cu, Zn, Pb, PAH, and suspended solids were most frequently Reported. In addition, high concentrations of road salt were found during snow smelt. Negative effects on the aquatic environment due to effects from road salt in contaminated snow were most pronounced. Handling of urban snow is difficult due to the elevated concentrations of contaminants. Today snow is dumped in all types of water courses, and methods to handle urban contaminated snow are missing. The municipality of Oslo is today delivering contaminated snow to a snow melting barge, which treats the contaminated snow before it is discharged into the Oslofjord. Other measures to reduce the contamination during snow melt are discussed.	2
[69]	Veiavrenning av glyfosat til overflatevann – et felt-, metode- og modelleringsstudie fra Holttjern Espen Haukeli Harald Johannes Foslien Løvstad	Thesis	2016	NO	Pesticides in road runoff	No	No	No	Not present	For a long time it has been allowed to use pesticides under roadside barriers to keep the vegetation short along Norwegian roads. There are several pesticides used for this purpose, but glyphosate is the pesticide most commonly used. Risk assessment for glyphosate runoff to water bodies which is near roads does not exist in Norway. The main purpose of this thesis is to assess the risk of glyphosate runoff from a sprayed road area, near the water body Holttjern. Glyphosate has strong adsorption to soil, especially clay, iron and aluminium. Contents of organic matter in soil is also of great importance for sorption. Because of glyphosate's strong bond to the soil, there will be mainly particle bound runoff and erosion. Pesticides can leach into the water and thus pose an environmental risk to aquatic organisms. In previous studies several cases of pesticide residues in water have been found. The toxicity of pesticides is expressed by environmental risk index (MF-values). These values are compared to our measured / predicted values for glyphosate and AMPA (risk assessment). In this thesis both field surveys (soil, water and sediment) and modelling with PRZM 5 is used to examine the findings of glyphosate and AMPA.	The approach to the problem for the field surveys is to see if there is glyphosate and AMPA in soil, water and sediment samples from Holttjern. The results of the field study show only low concentrations of glyphosate in soil. The highest concentrations in soil was found under the road barrier (121.1 ng/g of glyphosate and 423 ng/g of AMPA). In surface water, the highest concentration of glyphosate (0.0196 µg/L) was found in the middle of Holttjern (in between the inlet and outlet). For AMPA the highest concentration was found at the inlet (0.0275 µg/L). As a part of the risk assessment, and to assess the suitability of the model to describe the situation at Holttjern, the exposure of glyphosate and AMPA was simulated. With these simulation results and field observations from Holttjern, one can conclude that neither glyphosate nor AMPA exceed the MF-values for aquatic organisms or ADI for humans.	2

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[70]	*Kjemisk karakterisering av sediment i rensebassenger for vegavrenning* Av Susanne Lund Johansen, Helene Thygesen, og Sondre Meland	Paper	2014	NO	Monitoring of stormwater pond sediment concentrations (metals, carbohydrates)	No	No	No	Not present	Chemical characterization of sediment in wet sedimentation pond receiving highway runoff. Sediment was sampled from 19 wet sedimentation ponds for highway runoff. The samples were analysed for metals, hydrocarbons and polycyclic aromatic hydrocarbons (PAH), and characterized according to the classification system for environmental quality, developed by the Norwegian Environment Agency. The environmental quality in five ponds was moderate, poor or very poor because of elevated concentrations of metals (particularly copper and zinc) or PAHs. The environmental quality in the remaining ponds was characterized as natural state or good. Four ponds had a sediment pollution index higher than 1, which means that the Predicted No Effect Concentration (PNEC) values of nickel, copper, zinc, cadmium and lead on average were exceeded. The variation in pollution level is difficult to explain, as no correlation was found between traffic load or pond surface area, and pollution level.	The study has shown that the stormwater ponds have the ability to capture particulate contaminants in runoff water from roads. Pollution rates in the sediments from the majority of the ponds can be classified as natural or good for metals and PAH. The ponds Kambo, Vikshaugen and Frogtunnelen, and partly Bjørnstadgrenda, stand out with poor or very poor environmental quality for up to several substances. These ponds have a pollution index that exceeds 1, that is, the average PNEC values for Ni, Cu, Zn, Cd and Pb are exceeded. There was no clear connection between traffic volume and pollution rate in this study. Good operating procedures for the treatment ponds are necessary to protect the life of the recipient and to prevent remobilization of sedimentary contamination.	2
[71]	Hans-Jörg Lutz (2017) *Evaluation der Gewässerbelastungen durch Ableitungen von Autobahnabwasser im Bereich des Zweckverbandes ARA Untermarch*	Report	2017	GE	Monitoring highway runoff discharges (metals, PAH)	No	No	No	Not present	An overall assessment has been made on the problem of highway runoff discharges from the A3 into the contributing waters to the lake Obersee in the area of the Zweckverband ARA Untermarch. The present study on the emergence of environmentally hazardous substances, which washed off from the motorway section Untermarch in rainy weather and reach the upper lake, provides the basis for the development of a measure concept. It is undisputed that since the existence of the motorway a discharge of copper, zinc and cadmium as well as various polycyclic aromatic hydrocarbons has taken place and continues to take place. These substances then accumulate in the pond sediments. The pollutants deposited today in the lake are virtually non-degradable and remain at the place of enrichment. A reduction of the future pollutant inputs does not change the existing deposits, however, a further increase can be reduced or avoided.	The drainage of the A3 motorway in the Untermach section is subdivided into 14 different sized separate drainage sections, of which runoff is discharged either directly or through small streams indirectly in the upper lake. Critical protective substance parameters are undissolved substances (CIS) and the heavy metals copper (Cu), zinc (Zn) and cadmium (Cd) and polycyclic aromatic hydrocarbons (PAHs) derived from fuels and combustion products. While the dissolved and finely colloidal substances (nanoparticles) are rapidly mixed and diluted horizontally on discharge into a lake, a large proportion of the undissolved substances sediment around the points of discharge. The contaminants attached to the solids accumulate in the sediment. For the verification of the computationally recorded enrichments in the sediment, sediment investigations were carried out. Multiple cores around the discharge points and the chemical analyses of many substances by ICP and analyses of PAHs (16 PAHs according to EPA) show that the transport related elements Cu, Zn, Cd and the PAHs show markedly elevated concentrations in the first 10 - 15 cm of sediment samples. In comparison, the targets of the ICPR and VBBo for Zn are exceeded by factors of 1.5 -2.5 in all samples, 1.5 - 2 times for Cu in all samples, 1.5 times for Cd in Altendorfer samples, and 1.5 times for PAHs exceeded in the two analysed samples by 4 - 6 times. The concentrations for the benzo (a) pyrene, which is also regulated in the VBBo, are twice the guideline value. The ICPR target of 0.4 mg benzo (a) pyrene / kg TS is currently being achieved.	2
[72]	Brenčič M., Ratej J., Bole Z., Herič J., Gale U. (2004) *Influence of traffic load on the pollution of highway run-off* (in Slovenian Vpliv prometnih obremenitev na obseg onesnaženosti odpadnih voda z avtocest)	Report	2004	SI	Yes. In the frame of the study values of snow composition on highway and run-off generated during snow thawing were measured in several sections around Ljubljana with special sampler. Measured were basic physical parameters, trace elements and organic pollutants.	Attempt was made to establish relation between traffic load and chemical composition of run-off.	Yes	Yes	In the study sites around Ljubljana, central Slovenia were included. Average precipitation for the area is around 1500 mm/year with winters with snow. The area is positioned in the transition between Mediterranean influences and alpine climatic regimes. Sites were positioned on two types of aquifers; one type was unconfined gravel aquifer which represents main source for drinking water supply to the city of Ljubljana. The other type of sites was positioned on the clay and marly soils representing cover to the confined aquifer which is also used for water supply. In all cases study was performed on 2 x 2 lane highway with heavy traffic between 40.000 and 60.000 ADT.	Study reviewed values on the chemical composition of highway run-off from domestic and foreign literature.The research Report was directed toward the analysis of open questions in relation to possible highway pollution in related to the run-off. Paper summarised open questions and further directions in relation to better understanding of chemical composition of run-off from highway and how it possibly influences water resources especially groundwater which in Slovenia represents the main drinking water resource. At the time when Report was finished open questions were related to chemical composition of run-off, emission characteristics in relation to run-off, models of emissions relevant for the chemical composition of run-off and how to relate chemical composition of run-off and traffic load.	Conclusions of the study were directed toward the data gap analysis. In the relation to run-off quality emphasis was given toward better sampling techniques. Large part of the concluding discussion was also related to the problem of the prediction of the chemical quality of run-off.	4
[73]	Kogovšek J. (2007) *Influences of traffic on karstic waters (in Slovenian: Vpliv prometa na kraške vode)*. In: Knez M. & Slabe T., 2007: Karstic phenomena uncovered during the construction of Slovenian highways. ZRC SAZU	Book chapter	2007	SI	Study summarised results of previous investigations of run-off on karstic area.	No	Yes	Yes	Chapter summarise results of run-off studies performed on karstic area of Slovenia which in fact represents 50% of state's land. It is highly vulnerable area where practically no soil cover is present, therefore, infiltration is very fast and there is no retention in the surface of the soil. On the karstic area high precipitation is present from 2000 mm/year to 4000 mm/year in high mountains. Snow cover is often present during the winter in mountains it can be more than 1 m. Highways crossing karstic area 2x2 lanes with lanes for slow vehicles on higher slopes. ADT is up tu 50.000	Book chapter in details summarise results of investigations performed on the highway Ljubljana Kope crossing sensitive area of recharge zone of sprimg Rižana supplying whole coastal area of Slovenia. Results are similar to other works of Kogovšek given in the table, however details given in the each of them are differing an as a whole can give the whole picture. This was also the first study performed on highway run-off in Slovenia.	Book chapter illustrates characteristics of road run-off on highways crossing karstic area.	3
[74]	Kogovšek J. (2011) *The impact of traffic on karst waters*. In: Prelovšek, M., & Hajna Zupan, N.: Pressures and Protection of the Underground Karst - Cases from Slovenia nd Croatia. ZRC SAZU, 119-128	Book chapter	2011	SI	Study summarised results of previous investigations of run-off on karstic area.	No	Yes	Yes	Chapter summarise results of run-off studies performed on karstic area of Slovenia which in fact represents 50% of state's land. It is highly vulnerable area where practically no soil cover is present, therefore, infiltration is very fast and there is no retention in the surface of the soil. On the karstic area high precipitation is present from 2000 mm/year to 4000 mm/year in high mountains. Snow cover is often present during the winter in mountains it can be more than 1 m. Highways crossing karstic area 2x2 lanes with lanes for slow vehicles on higher slopes. ADT is up to 50.000	Book chapter in details summarise results of investigations performed on the highway Ljubljana Kope crossing sensitive area of recharge zone of sprimg Rižana supplying whole coastal area of Slovenia. Results are similar to other works of Kogovšek given in the table, however details given in the each of them are differing an as a whole can give the whole picture. This was also the first study performed on highway run-off in Slovenia.	Book chapter illustrates characteristics of road run-off on highways crossing karstic area.	3

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[75]	Kogovšek J. (2011) *Threats to the karst water sources from traffic in normal conditions*. In Knez M., Petrič M., Slabe T.: Karstology and development challenges on karst I: Water, 47-64	Book chapter	2011	SI	Study summarised results of previous investigations of run-off on karstic area.	No	Yes	Yes	As above	As above	As above	3
[76]	Kompare B., Atanasova N., Babič R., Panjan J., Bulc T., Cerar U., Rodič P., Knez M., Kogovšek J., Petrič M., Pintar, M. (2002) *Highway drainage and protection of waters: analysis of treatment pond on karst. (In Slovenian: Odvodnja avtocest in zaščita voda : analiza delovanja čistilnega objekta na krasu)*. In: Vilhar M. (ed.). Proceedings of 6th Slovenian Congress on Roads and Traffic , Portorož, 10/2002, 93-102.	Conference Proceeding	2002	SI	Yes. Chemical status of run-off waters was measured at the inflow into retention pond. Quality of retention pond water and sediments were measured. Key pollutants: COD, BOD, heavy metals, AOX, PAH, BTX, mineral oil.	No	Yes	Yes	Paper is focusing on the run-off from highway crossing karstic area in the relation between Ljubljana (central Slovenia) and Koper (coastal area) where big port is positioned. There is dense traffic with large share of heavy trucks delivering goods to the port. During summer months there is heavy traffic of cars going from Central Europe to the sea side of Croatia and Slovenia. It is 2x2 lane with side lines for slow vehicles on higher slopes. Precipitation amount is in around 1500 mm/year with intensive summer showers.	Detailed Report of highway run-off investigation as in other Papers of Kogovšek. More technical details are given than in the Papers of Kogovšek.	Paper illustrates empirical data of highway run-off and characteristics of water and sediments in the retention pond. Results are important because they are representing data on karstic area	4
[77]	Brenčič M. (2006) *Groundwater and highways interaction: past and present experiences of highway construction in Slovenia.* Environmental Geology, 49(6), 804-813	Paper	2006	SI	No. Impacts on water bodies were estimated based on their spatial relations.	No	Yes	Yes	Paper deals with Slovenia as a whole. Sloveni is representing as a country rich in waters and where nearly water supply is coming from groundwater. Consequently there are many potential conflicts between drinking water protection zones and roads. Half of the country is covered by carstic aquifers, between 20 and 30 % is represented by intergranular aquifers which are unconfined and of high yield. Precipitation in the country is from more than 4000 mm/year on the mountainous region to 800 m/year on the Pannonian plain where continental climatic regime is already emplaced. Roads are of different characteristics. In some parts highways have 70.000 ADT in other main highway lanes it is not rising over 40.000 ADT.	During the planning, designing, construction, operation and maintenance of highways, groundwater can be of important environmental and constructional constraint that can significantly influence the safety operation of traffic and of big influence on the operational costs of highways. To classify and conceptualize the relation between groundwater and highways, three important groups of problems can be determined: groundwater protection from highway influences, protection of highway from groundwater and economic use of groundwater for highway operation. In the present study, groundwater management strategies are represented during all life cycles of highways. Greater emphasis is given to groundwater protection and field hydrogeological investigations for proper groundwater management related to the highway. The approach adopted in Slovenia and the role of hydrogeology is given as an illustration.	Paper has summarised experiences on the groundwater protection from roads	3
[78]	Brenčič M. (2001) *An analysis of standardized measures for the protection of drinking water resources from the negative impacts of roads,* Acta hydrotechnica, 2001, 19(31),137-153	Paper	2001	EN	No. Study analysed relations between drinking water protection zones and highway network.	No	Yes	Yes	Paper is focusing on the run-off from highway crossing karstic area in the relation between Ljubljana (central Slovenia) and Koper (coastal area) where big port is positioned. There is dense traffic with large share of heavy trucks delivering goods to the port. During summer months there is heavy traffic of cars going from Central Europe to the sea side of Croatia and Slovenia. It is 2x2 lane with side lines for slow vehicles on higher slopes. Precipitation amount is in around 1500 mm/year with intensive summer showers.	Slovenia has a number of drinking water resources, with their protected water recharge areas extending over a large part of the Slovenian territory. Consequently, roads and traffic often run within these areas, and are subject to numerous restrictions imposed by drinking water resource protection regulations. This article gives an analysis of these regulations and divides them into six groups: restrictions of road and manoeuvring area construction, technical and engineering requirements for ground water protection, traffic speed restrictions, restrictions of transit transport, restrictions of the transport of dangerous and harmful substances, and requirements for setting up traffic signs. The properties of each group are briefly described and analysed, and the representation of each group in the analysed water protection acts is given.	Paper has summarised experiences relations to drinking water protection zones.	3
[79]	Marhold P. (2011) *Methodology for highway run-off treatment (in Slovenian: Metodologija ravnanja s padavinskimi vodami na avtocestah)*. Univerza v Mariboru, Fakulteta za strojništvo, 208 pp.	Thesis	2011	SI	Yes. Chemical status of run-off waters was measured at the inflow into retention pond. Quality of retention pond water and sediments were measured. Key pollutants: COD, BOD, heavy metals, AOX, PAH, BTX, mineral oil.	Attempt was made to establish relation between traffic load and chemical composition of run-off.	Yes	Yes	The site is positioned in NE Slovenia at the area where two large highway are joining; one from the direction of Hungary, another from the direction of Austria. Total traffic load is not higher than 30. ADT. Precipitation amount is around 1000 mm/year. The site is positioned near the small river and there is no significant aquifer.	Thesis in the first part summarise literature data on pollutants originating from road run-off. This summary is followed by the review of present natural conditions and road characteristics at the state level. In the main part Paper is describing approach and methodology of investigation related to road run-off at particular site and illustrates results of these measurements.	Paper illustrates empirical data of highway run-off and characteristics of water and sediments in the retention pond.	4
[80]	Žgajnar A., Kompare B., Zagorc J. (2009) *Influence of run-off water from the system of highway on environment (In Slovenian: Vpliv odpadnih vod avtocestnega sistema na okolje)*. In: Roš M. (ed). Vodni dnevi 2009, Portorož, 21–22 oktober 2009, Ljubljana, 47–58	Conference Proceeding	2009	SI	Yes. Chemical status of run-off waters was measured at the inflow into retention pond. Quality of retention pond water and sediments were measured. Key pollutants: COD, BOD, heavy metals, AOX, PAH, BTX, mineral oil.	No	Yes	Yes	The investigated site is positioned in the alluvial aquifer with high yield. The aquifer is representing main water resource for drinking water supply of the city of Ljubljana (capital of the country). Precipitation amount is around 1500 m/year. Site is positioned near the highway with heavy traffic. This road is one of the most loaded roads in Slovenia. The load is over 60.000 ADT.	In the first part Paper summarise literature data on pollutants originating from road run-off. This summary is followed by review of legislation. In the main part Paper is describing approach and methodology of investigation related to road run-off at particular site and illustrates results of these measurements. They have performed also laboratory investigation on water collected at the site with the aim to identify possible remediation measures.	Paper illustrates empirical data of highway run-off and characteristics of water and sediments in the retention pond.	4

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[81]	Brenčič M., Rikanovič R. (2002) *Groundwater and road network interactions - case study from Slovenia,* Geologija, 45(2), 325-330	Paper	2002	EN	No. Impacts on water bodies were estimated based on their spatial relations.	Yes. Modelling related to the spatial dimension of roads.	Yes	Yes	Paper is focusing on the run-off from highway crossing karstic area in the relation between Ljubljana (central Slovenia) and Koper (coastal area) where big port is positioned. There is dense traffic with large share of heavy trucks delivering goods to the port. During summer months there is heavy traffic of cars going from Central Europe to the sea side of Croatia and Slovenia. It is 2x2 lane with side lines for slow vehicles on higher slopes. Precipitation amount is in around 1500 mm/year with intensive summer showers.	The Paper analyses the potential impacts of various state roads on aquifers in Slovenia. A short introduction about groundwater protection standards and an overview of current practice of groundwater protection from road network impacts is given. On the state level, the hydrogeological conditions were analysed according to the various categories of roads that cross them. According to this analysis, the ratio of the impact potential of the aquifer crossed by a road type is calculated on the state level. The ratio is represented as the quotient between the share of aquifer crossings by a type of roads and the share of a particular aquifer on the state level.	Paper has illustrated relative load of road and road traffic on different types of aquifers.	3
[82]	Brenčič M. (2004) *Crossing of drinking water resources protection zones by roads (in Slovenian: Prečkanja cest preko vodovarstvenih območij),* Geologija, 47/2, 273-281	Paper	2004	SI	No. Study analysed relations between drinking water protection zones and highway network.	Yes. Modelling related to the spatial dimension of roads.	Yes	No	Paper is focusing on the run-off from highway crossing karstic area in the relation between Ljubljana (central Slovenia) and Koper (coastal area) where big port is positioned. There is dense traffic with large share of heavy trucks delivering goods to the port. During summer months there is heavy traffic of cars going from Central Europe to the sea side of Croatia and Slovenia. It is 2x2 lane with side lines for slow vehicles on higher slopes. Precipitation amount is in around 1500 mm/year with intensive summer showers.	Crossing of drinking water protection zones by roads are very common phenomenon in Slovenia. Described are starting points for protection of drinking water resources implemented with new legislation. In the article emphasize is given on the road and drinking water interaction. This new legislation implements also procedures for new construction impact assessment on protected drinking water resources. Assessments are defined as risk analysis. Some theoretical bases for these procedures are given.	Paper has illustrated principles of groundwater protection from possible negative impacts of roads on groundwater.	3
[83]	Brenčič M. (2004) *Clasiffication of pollutants originating from roads (In Slovenian: Razvrstitev onesnaževal, ki izvirajo s cest),* In: Vilhar, M. (ed.). Proceedings of 7th Slovenian Congress on Roads and Traffic, Portorož, 20-22 oktober 2004, Ljubljana, 537-541	Conference Proceeding	2004	SI	No. Study has made an attempt to classify various pollutants related to roads and traffic.	No	No	No	Paper is not dealing with any particular road or site.	Paper deals with theoretical aspects of pollutants originating from roads which can influencing water environment.	Paper illustrates complexity of pollutants originating from roads.	3
[84]	Zafra C., Temprano J., Suárez J. (2017) *A simplified method for determining potential heavy metal loads washed-off by stormwater runoff from road-deposited sediments*, Science of total environment 601-602, 260-270	Paper	2017	EN	Monitoring study of road deposition sediments. The authors considered 2 sections in 2 roads (total of 4 study areas). The roads were located in Spain and Colombia. Particle size distribution, leaching test and digestion method and heavy metals content in the sediments were assessed. The focus of the Paper was on the following heavy metals: Pb, Zn, Cu, Cr, Ni, Cd, Fe, Mn, Co, and Ba.	A simplified method for determining the potential load of ehavy metals derived from wash-off caused by runoff on road deposited sediments was developed. Do not transfer to task 1.2. Transfer to task 1.5.	No	Yes but of limited use for the present project as data was obtained from leaching tests in the lab	The road surfaces for developing the simplified method were located in the cities of Torrelavega, Spain (A1) and Soacha, Colombia (A2). Road deposited sediments were collected next to the curb in dry weather at the same time each day.Each road surface had two sections: A11 and A12, and A21 and A22, respectively. These study areas were selected because the climate conditions, road-traffic density, and land use were different for each road surface. Primary climate and physical characteristics for each road are presented in table 1 of the Paper. In A1, the Atlantic climate (warm) is characterized by abundant yearlong rains, high humidity, and mild temperatures. In A2, the tropical mountain climate (cold) is characterized by abundant yearlong rains and a wide variation in temperature (hourly variation: 5–22 °C).	A simplified method is proposed for determining the potential load of heavy metals (HMs) derived from the wash-off caused by surface runoff on road-deposited sediment (RDS). The method consists of three phases: (i) characterization of RDS load wash-off, (ii) assessment of HM load in dry weather, and (iii) application of a wash-off equation. Two processes were included in the wash-off equation: HM transport (solid fraction) and HM leaching (dissolved fraction). The average wash-off of HMs ranges from 16.6 to 46.3%, relative to the total mass of HMs associated with dry-weather RDS (Pb, Zn, Cu, Cr, Ni, Cd, Fe, Mn, Co, and Ba). Cd, Mn, and Zn presented the highest wash-off in the areas studied. The size fraction below 250 μm contributed an average of 86.7% of potential HM load washed-off from RDS. Based on the phenomena included in the wash-off equation, it was observed the following order of precedence: transport of RDS b 250 μm, leaching of RDS b 250 μm, and leaching of RDS ≥ 250 μm. Solid and dissolved fractions contributed 70.7 and 29.3% of the potential HM load washed-off by runoff from RDS, respectively. The proposed method serves as a management tool for road HM pollution during rain.	This Paper presents a simplified method for determining the potential load of heavy metals derived from wash-off caused by runoff on road deposited sediments. The potential load of HMs washed-off by runoff from RDS averaged between 16.6 and 46.3% relative to the total mass of HMs associated with dry-weather RDS. The HMs with the highest wash-off are: Cd, Mn, and Zn. These HMs consistently show the highest percentages of leaching in laboratory tests. Solid and dissolved fractions contribute 70.7 and 29.3% of the potential HM load washed-off by runoff from RDS, respectively.	3
[85]	Guide Technique. *Pollution d'origine routiére.Conception des ouvrages de traitment des eaux.* Service d'Ètudes Techniques des Routes et Autoroutes (SETRA)	Report	2007	FR	No monitoring results	Presents a method (equations) established to predict annual road runoff pollutant loads (for French sites). Yes	Also presents a method for the evaluation of receiving water vulnerability	No		It presents a simple method to calculate road runoff loads (kg/ha) for SS, COD, Zn, Cu, Cd, Total Hydrocarbons and HAP. It splits annual road traffic volume in below and above 10 000. Equations based on monitoring studies from Setra, since 1992. Also calculates average annual concentrations road runoff discharge. It uses a classification of “open” and “restricted” roads, differentiating the sections that are excavated (restricted) where more likely particles are dispersed. Also has an equation for calculation of average annual concentration of the pollutants in road runoff. This calculation is based on the annual load (kg), impervious surface (ha), average annual rainfall depth (m) and a factor/rate of reduction of works.	SETRA gives guidelines to be used at a National Level, therefore the work is very valuable because summarizes the French approach, most relevant pollutant parameters, and typical or average levels of pollutants (annual loads and annual concentrations). It has an example of calculation. Contains also relevant information regarding the approach to receiving water bodies, within WP2	2
[86]	Kayhanian M., Suverkropp C., Ruby A., Tsay K. (2007) *Characterisation and prediction of highway runoff constituent event mean concentration,* Journal of Environmental Management, 85(2), 279-295	Paper	2007	EN	Yes. 34 highway sites from California monitored during 2000-2003. Average 8 events/site/wet season of the year. pH, cond, hardness, ; SS, DS, OC, DOC, total & diss metals (As, Cd, Cr, Cu, Ni, Pb and Zn). Nutrients: NO3, TKN, total P and ortho-P.	Yes: multiple linear regression (MLR) analysis and MLR model predictors for EMC of all parameters. Yes	No	Yes	California is placed at a similar latitude as Southern Europe. Average annual rainfall range:152-1016 mm. Average catchment area range: 0.01-5,95 ha. Average annual daily traffic range: 1800-322000. Surrounding land use types: Agriculture; rural, commercial, residential. Samples were analysed for conventional pollutants (pH, conductivity, hardness, and temperature); aggregates (TSS, TDS, TOC, DOC); total and dissolved metals (As, Cd, Cr, Cu, Ni, Pb, and Zn); and nutrients (NO3–N, TKN, total P, and ortho-P).	Highway stormwater runoff quality data were collected from throughout California during 2000–2003. Constituent event mean concentrations (EMCs) were generally higher in urban highways than in non-urban highways. The chemical characteristics of highway runoff in California were compared with national highway runoff chemical characterization data. Multiple linear regression (MLR) analyses were performed to evaluate the impact of various site and storm event variables on highway runoff constituent EMCs. Parameters found to have significant impacts on highway runoff constituent EMCs include: total event rainfall (TER); cumulative seasonal rainfall (CSR); antecedent dry period (ADP); contributing drainage area (DA); and annual average daily traffic (AADT). Surrounding land use and geographic regions were also determined to have a significant impact on runoff quality. The MLR model was also used to predict constituent EMCs. Model performance determined by comparing predicted and measured values showed good agreement for most constituents.	Very relevant Paper. Although not data from Europe it represents climate regions similar to Southern Europe and a comparison with other sites in the USA. Also interesting to link with the PROPER tasks 1.2 and 1.4, since it presents a method to predict highway runoff constituents.	5

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[87]	Charters F., Cochrane T., O'Sullivan A. (2016)*Untreated runoff quality from roof and road surfaces in a low intensity rainfall climate, Science of the Total Environment,* 550, 265-272	Paper	2016	EN	Yes. 4 different urban surfaces monitored in New Zealand. 3 urbanized areas and an asphalt road. Grab and automatic sampling. 24 rainfall events from December 2013 to March 2015. TSS and total heavy metals: Cu, Pb and Zn.	No	No	yes (few)	All events were <= 4.7mm/h. Christchurch's climate is semiarid. Average annual rainfall is 647mm and average of 647mm/year rainfall. Initial 2L runoff collected (first flush calculation). Sites close to each other but with different roof characteristics (concrete, copper, galvanized) and an asphalt road (4 sites).	The study describes the TSS and heavy metal concentrations found in runoff from four different urban surfaces within a residential/institutional catchment, in a climate where rainfall is typically of low intensity (<5.1 mm·h−1). Pollutant concentrations were found to be significantly different between surfaces; quantification and prediction of pollutant contributions from urban surfaces should thus take account of the different surface materials, instead of being aggregated into more generalized categories such as land use.	The TSS and heavy metal concentrations were found to be at the low to medium end of ranges observed internationally, except for total copper and zinc concentrations generated by dissolution of copper and galvanized roofing material respectively; these concentrations were at least as high as those Reported internationally. A first flush effect was seen from most surfaces for TSS, but not for heavy metals. This study demonstrates that in low intensity rainfall climates, quantification of untreated runoff quality from key individual surface types in a catchment are needed. Relevant because brings out the attention to the specificity of construction materials and not just land use type, in the understanding of road runoff quality.	2
[88]	Markiewicz A., Björklund K., Eriksson E., Kalmykova Y., Strömvall A., Siopi A. (2017) *Emissions of organic pollutants from traffic and roads: Priority pollutants selection and substance flow analysis,* Science of The Total Environment, 580, 1162-1174	Paper	2017	EN	No monitoring results	No	No	No	No	The aim of the study was to establish a list of significant sources of organic pollutants occurring in road runoff, identify the OPs emitted from these sources, select a number of priority pollutants (PP), and estimate the quantity of PPs emitted in a road environment case study using substance flow analysis (SFA). PAHs were chosen for a SFA, which was performed for a highway case study area in Gothenburg (Sweden). The SFA showed that the main sources of PAHs emitted in the area were vehicle exhaust gases, followed by tyre wear, motor lubricant oils, road surface wear, and brake linings. Only 2–6% of the total 5.8–29 kg annually emitted PAHs/ha ended up in the stormwater sewer system. The measured PAH loads were found in much smaller amounts than the calculated loads and the outflow to stormwater contained much more of the hazardous PAHs than the total loads emitted in the catchment area.	Not so relevant because theoretical study on comparison of emission/calculated loads of PAHs with the measured ones	1
[89]	Maharjan B., Pachel K., Loiguet E. (2017) *Modelling stormwater runoff, quality, and pollutant loads in a large urban catchment*, Proc. of the Estonian Academy of Sciences, 66(3), 225–242	Conference Proceeding	2017	EN	Monitoring results for 3 events at a 10,24 km 2 sub catchment of Tallin city (Estonia capital). 14,4% of the catchment area is road. Rainfall and runoff monitoring data and TSS and TP. Monitoring took place in 2014 and 2015.	Yes. The model SWMM (Stormwater management model) was used. The model developed in SWMM had a good performance for quantity estimation, but the quality results. Info can be used in Task 1.2 were of moderate accuracy.	No	Yes	Mustoja basin is an urban catchment of 10,24 k2 of which 14,4% (147,5 ha) is represented by road land use. Residential area is the largest land use (47,1%= 481,8 ha). Total annual rainfall=704 mm; average monthly rainfall ranges from 32 mm (April) to 86 mm (August). It snows from mid December to late March. The 3 events monitored had different characteristics: 1) duration=2,3h and 5,1mm; 2) duration=26h and 6,2mm; 3) duration=13,5h and 9,7mm.	In this study, the stormwater management model SWMM5 is applied for model development for a large basin in Tallinn. The model is calibrated and verified using three sampled storm events to estimate event mean concentrations and annual loads. The predictive capability of the model for quantity is good and for quality moderate. Although directly connected impervious area, in particular roads and roofs, have relatively smaller areas they significantly impact runoff production (up to 75%) and loads (up to 66% total phosphorus and 71% total suspended solids). The first flush at the beginning of runoff is less important in case of a low intensity of rainfall, but heavy rain and snowmelt generate substantial runoff and pollution loads. When grab sampling is applied, it should focus on the medium and large events within 6 hours of storm commencement in order to achieve better mass estimations.	Although regarding an urban catchment it is interesting because is data from Estonia (not so much available), providing detailed land use, rainfall and pollutants figures. It can feed the testing of modelling tools.	3
[90]	Boogaard F., de Ven F., Langeveld J., de Giesen N. *(2014) Stormwater Quality Characteristics in (Dutch) Urban Areas and Performance of Settlement Basins*, Challenges, 5, 112-122	Paper	2014	EN	Based on a huge stormwater pollution monitoring study in The Netherlands, that monitored over 150 locations throughout the country for 15 years and a total of 7,652 events.TSS, BOD, COD, TKN, TP, Pb, Zn, Cu, Ecoli and particle size analysis.	No	No	Yes. Mean, median and 90 percentile concentrations	No	Knowledge of stormwater pollution enables the good choice of the most appropriate stormwater management strategies to mitigate the effects of stormwater pollution on downstream receiving waters. This requires detailed information on stormwater quality, such as pollutant types, sediment particle size distributions, and how soluble pollutants and heavy metals attach themselves to sediment particles. This study monitored stormwater pollution levels at over 150 locations throughout the Netherlands. The monitoring has been ongoing for nearly 15 years and a total of 7,652 individual events have been monitored until 2014. This makes the database the largest stormwater quality database in Europe. The study compared the results to those presented in contemporary international stormwater quality research literature. The study found that the pollution levels at many of the Dutch test sites did not meet the requirements of the European WFD and Dutch Water Quality Standards.	Although regarding urban stormwater is relevant for informing on what is assumed to be the largest database stormwater quality database in Europe. It has a table with concentrations (mean, median and 90 percentil) of between 60 to 1262 measurements for the several parameters, regarding Dutch residential areas. Also includes a table comparing mean and median concentrations of stormwater pollutants in Dutch, Europe/Germany and worldwide.	2
[91]	Zgheib S., Moilleron R., Ghassan C. (2012) *Priority pollutants in urban stormwater: Part 1 - Case of separate storm sewers,* Water Research, 46(20), 6683-6692	Paper	2012	EN	Stormwater pollution monitoring three separate storm sewers in Paris. Metals, PAHs, PCBs, organotins, alkylphenols, phthalates, pesticides, and VOCs. Analyses conducted on both the particulate (P) and dissolved (D) phases.	No	No	Yes. Tables with range & median of pH, Conductivity, S, COD, KN and Ptot, Pb, Cu, Zn, 16 PAH 7 PCB, and more	No	This study provides results on stormwater pollution in Paris and its suburbs from three separate storm sewers (n ¼ 20 samples). 20 storms monitored between February 2008 and March 2009 for the 3 catchments; only 16 provided usable results. These results show that the stormwater had been contaminated by 55 chemical substances. Concentrations are provided for: metals, PAHs, PCBs, organotins, alkylphenols, phthalates, pesticides, and VOCs. the relevant analyses were all conducted on both the particulate (P) and dissolved (D) phases. For most substances, particles from the three storm sewers were more heavily contaminated than dredged sediments and settleable particles from the Seine River. As a consequence of this finding, the release of untreated stormwater discharges may impact the receiving waters and contribute to sediment contamination.	Interesting for the purpose of an European overview, although probably the data cannot be used in PROPER (too densely urbanised catchments).	2
[92]	Modugno M., Gioia A., Gorgoglione A., Iacobellis V., Forgia G., Piccinni A., Ranieri E. (2015)*Build-Up/Wash-Off Monitoring and Assessment for Sustainable Management of First Flush in an Urban Area,* Sustainability 2015, 7, 5050-5070	Paper	2015	EN	Experimental study area in Sannicandro di Bari, a small town in Puglia (Southern Italy). Drainage area=31.24 ha and covers approximately 60% of the total urban area; has 21.87 ha (70%) of impervious surface. 3 events monitored (Nov 2006; Jan 2007). Rainfall data and sample collection. Parameters: BOD5, COD, SS, Ntot, P, Pb and Cu.	Yes. The model SWMM (Stormwater management model, version 5.0) was used. The model developed in SWMM was calibrated only based in 3 events. The info can be used in Task 1.2	No	Yes	Experimental study area in Sannicandro di Bari, a small town in Puglia (Southern Italy). Drainage area is 31.24 ha and covers approximately 60% of the total urban area; has 21.87 ha (70%) of impervious surface. Events: 1) duration 50 min, 2,4mm; 2) duration 113 min, 4,3 mm; 3) duration 39 min, 1,6 mm.	In order to make a characterization of stormwater runoff a monitoring campaign was carried out within a residential area in Puglia (Southern Italy) in order to collect and evaluate quantity and quality data. A strong correlation was observed between COD (Chemical Oxygen Demand) and TSS (Total Suspended Solid) concentrations, whose values exceed water quality standards. TSS was used for calibration of Storm Water Management Model (SWMM version 5.0) which was then validated with reference to the pollutograph's shape and the peak-time. Results show that on average the first 30% of that washed off carries 60% of TSS and provides important information for the design of efficient systems for first flush treatment.	Few results (3 events) but provides figures for the data obtained. Although it is an urban catchment, it provides info from Italy.	2

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[93]	Sage J., Bonhomme C., Al Ali S., Gromairet M. (2015) *Performance assessment of a commonly used "accumulation and wash-off" model from long-term continuous road runoff turbidity measurements*, Water Research, IWA Publishing, 2015, 78, pp.47-59.	Paper	2015	EN	Yes, only turbidity measurements were considered (and correlation with TSS)	Yes	No	No	The experimental site is located in "Sucy-en-Brie" municipality,a residential district within Paris conurbation. Thestudied catchment consists in an 800 m2 portion (½ roadwaywidth þ sidewalk) of an urban road carrying moderate trafficloads (~8000 vehicles per day), with a runoff length of 160 mand an average slope of 0.8%. Runoff was collected by a stormdrain where the monitoring equipment was installed. 11-litrestipping buckets were used for flow-rate measurement correspondingto a 0.014 mm resolution in runoff height overdrainage area.	The suitability of a commonly used accumulation and wash-off model for continuous modelling of urban runoff contamination was evaluated based on 11-month turbidity and flow-rate records from an urban street. Calibration and uncertainty analysis were performed using a Markov Chain Monte-Carlo sampling method for both suspended solids loads (discharge rates) and concentration modelling. Selected models failed at replicating suspended solids concentration over the complete monitoring period. The studied dataset indeed suggests that the accumulation process is rather unpredictable and cannot be satisfactorily represented with usual accumulation models unless short periods are considered. Regarding suspended solid loads modelling, noticeably better performance was achieved, but similar results could as well be obtained with much simpler constant concentration models. Unless providing very accurate estimates of concentrations in runoff, accounting for their temporal variability during rain events may therefore not always be necessary for pollutant loads modelling, as loads are in fact mostly explained by runoff volumes.	The accumulation and wash-off model used (SWMM) did not manage to correctly replicate TSS concentrations for the 11-month period. Calibration was presumably hindered by an important increase of sediment deposition at the beginning of the monitoring period. The model, which assumes that accumulation solely depends on dry period between rain events, was thus unable to correctly simulate this process.The predictive power of the model was only consistent for very limited set of rain events.While assuming that sediment deposition and erosion occurs at steady rate might be acceptable for larger catchments (where the variability of sediment inputs may be smoothed), the results presented in this Paper suggest that accumulation should rather be described as a stochastic process when small urban surfaces are considered.Eventually, suspended solid load predictions were relatively accurate despite the poor model performance for concentrations modelling. Accounting for fluctuations in TSS concentration during rain events may thus not systematically be relevant and respectable results can as well be obtained from very simple "event mean concentrations" models.Confrontation of the "accumulation and wash-off" model with long-term continuous water quality records therefore clearly indicates that its relevance for both concentration and loads modelling should seriously be questioned.	2
[94]	Helmreich B., Hilliges R., Schriewer A., Horn H. (2010) *Runoff pollutants of a highly trafficked urban road – Correlation analysis and seasonal influences*, Chemosphere 80, 991–997	Paper	2010	EN	Yes, Samples were immediately taken to the laboratory after each storm event and further analysed for their water quality parameters. All analyses were carried out according to the standard methods. Concentrations of copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), cadmium (Cd), and sodium (Na) were obtained. TSS, pH, Total organic carbon (TOC) and dissolved organic carbon (DOC) were measured.	No	No	Yes, average values (not complete time series)	Sixty-three runoff samples were collected over a period of 2 years at a highly trafficked road in Munich with an average annual daily traffic (AADT) load of 57 000 vehicles/day. The major land use surrounding at the sampling site comprised residential housing, office buildings and a park. The connected catchment area on the sampling site was 400 m2 and consisted of two lanes with asphalt paving, one acceleration lane and one emergency lane. The speed limit was 60 km/h. Sampling took place directly after the runoff passed a gully pot in a 500 L plastic container which was washed with a 3% (V/V) solution of nitric acid prior to every use. An overflow system had been installed for this study in order to collect the first 400 L of each rain event, representing roughly one mm rainfall drained by the connected surface area.	The quality of road runoff at a highly trafficked road has been studied for 2 years. 63 storm events have been sampled and analysed. Besides pH value and electric conductivity the concentrations of zinc (Zn), copper (Cu), lead (Pb), nickel (Ni) and cadmium (Cd), both in dissolved and particulate form, de-icing salt, total and dissolved organic carbon (TOC and DOC), suspended solids (SS) have been monitored. Correlation analysis showed a significant relationship between the total metal concentrations with TOC and SS. A considerable seasonal increase in pollutant concentrations has been observed for Cu, TOC, SS, pH value and especially for Zn during the cold season. The mean values during winter time were multiple times higher than measured during the warm season. In contrast, the fractionation of heavy metals was not affected by seasonal variations, but remarkable fluctuations were observed between different rain events with dissolved fractions above 90%. As a result of this and due to the high pollutant load on fine particles, best management practices (BMPs) only implementing sedimentation are not recommended for treatment of heavily polluted urban road runoff. From the data obtained it can be concluded, that the de-icing salt has only a weak influence for higher pollutant concentrations. The increase of heavy metal concentrations occurs because of increased tear and wear due to application of gravel at cold weather conditions. No significant influence of the length of antecedent dry weather periods could be observed most likely due to street sweeping, winds and air turbulences caused by traffic.	Strong fluctuations were observed for the heavy metals, TOC, DOC, and SS, as well as for the electric conductivity. The detected concentrations of heavy metals greatly exceeded the threshold values established in German regulations. As a result, treatment prior to infiltration is required for road runoff from the sampling site. The statistical test revealed significant correlations between the levels of total heavy metals and TOC and SS, indicating the major role of particles in the transportation of other pollutant constituents. Furthermore, high concentrations of one heavy metal concurred with high responses for other heavy metals as well. Strong seasonal changes were observed for Zn, Cu, TOC, and SS with manifold concentration increases during the melt season. A significant increase of Zinc was observed between the mean concentrations in snow and rain-on-snow events compared to mean concentrations in rain events. This can be tracked back to galvanized surfaces that are more subject to weathering conditions than vehicle wear. Even though de-icing salt is often held responsible for increases in pollutant concentrations, in this study the effect of seasonal changes seems to have to be the major reason. In cold weather conditions the heavy metal concentration increases because of increased tear and wear due to application of gravel. The use of de-icing salt has only a weak influence. The concentrations of heavy metals but not their fractionation varied between different seasons but form storm event to storm event. The mean values for the dissolved fractions were below 30% for Cu and Zn. Pb was completely undissolved.	4
[95]	Aljazzar T., Kocher B. (2016) *GE* 6th Transport Research Arena, April 18-21, 2016	Paper	2016	EN	Yes, Each of the three motorways; A4, A555 and A61; carries a traffic density of about 70000 vehicle per day, which exceeds the average daily traffic (ADT) of the German motorways.	No	No	No	Each of the three motorways carries approximately 70,000 vehicles a day on 4 to 6 driving lanes; and they cover a broad range of truck participation in the total traffic load ranging from 5.4% to 19.8%	This Paper presents two means through which pollutants leave the road to the surrounding environment. Three German motorways were selected (A4, A555, and A61), where runoff and deposits were analysed to determine pollutant load moving into the roadside soil or into the drainage system. Each of the three motorways carries approximately 70,000 vehicles/day on 4 to 6 driving lanes. Sampling of runoff and deposition was done on monthly basis. Bulk deposition was collected in Bergerhoff vessels at two heights (1.5 m and 0.3 m above the ground) and in 1 m, 2.5 m, 5 m and 10 m distances from the road edge. The results showed that heavy metals as well as large amounts of mineral compounds are moving from the driving lanes into the roadside environment. This includes sodium from applying de-icing salts in winter seasons, which could be found in soil, dust and water samples. Calcium and iron were also detected in almost comparable concentrations. The annual deposition flow (bulk deposition) measured at a height of 1.5 m was higher than the comparative values for urban areas and background measuring points. The spatial distribution of material deposition showed clear differences between the three motorways. The pollutant load in deposition measured near the ground surface was higher than those measured at 1.5 m above the land surface. At all three sites, a clear negative correlation between pollutant load and the distance from the roadside could be found.	The results presented in this study considered only the fraction rather than concentration of substances in deposits. Soil samples depicted a decreasing trend of heavy metals with increasing distances from the road edge. As an example; the concentration of zinc, lead and copper showed a clear decreasing pattern with increasing distance from the road side, which was about five times higher than at 10 m distance from the road edge. Compared to the precautionary values of the German Federal Soil Protection and Contamination Ordinance of the Ministry for Environment the concentration of several heavy metals was substantially high. The impact of de-icing salts was clearly reflected in the elevated electrical conductivity surface soil than in deeper layers, and in soil samples that are closer to the road edge. On the other side, most of the background deposits samples exhibited bulk deposition values higher than the typical VDI ranges of the bulk deposition and heavy metals in rural and urban areas. It was found that heavy traffic share clearly impacted deposition rate of traffic-related emissions. The results show a continuous and considerable deposition of dust and spray water. The retention ability of the roadside environment provided by vegetation and soils varies according to the local conditions, but its efficiency is widely irrespective of these properties. This leads to contaminant enrichment near the roads, but also helps to decrease substantially the mass flow leaving this direct environment to groundwater and surface waters.	3

ID	Complete Reference	Type	Year	Country	Monitoring study? Brief resume of the study & key pollutants	Modelling study? Brief resume of the study & modelling tool.	Vulnerability of the receiving water body?	Available data?	Characteristics of the site	Resume	Conclusions	Importance
[96]	Barbosa A. E.; Fernandes J. N. (2012) *Comprison of the pollutante potential of two Portuguese highways located in different climatic regions*. National Laboratory for Civil Engineering.	Paper	2012	EN	Yes There is a brief resume of the study, climatic variables and major pollutants	No	No The focus of the study is on the comparison of the pollutant potential in two different Portuguese highways	Yes There are data in graphs and tables	Yes The location is present in the article, as well as the average annual precipitation	This paper does not aim to explore the analysis of the two case studies (A1 and A22) or to quantify the relationships between variables, but rather to provide information on the climatic variables controlling the pollutant potential. Here was studied the above mentioned highways, which are located in different climatic regions, one in the centre of Portugal (A1) and one in the South (A22). Thus, climatic variables were evaluated in order to verify how they influence the pollutant load caused by highway runoff. Methodologically, 6 to 8 samples were analysed in 10 or 11 runoff events, and 18 parameters were analysed. Of these 18 parameters, only 5 were analysed in the article: TSS; COD; Cu; Fe and Kjeldahl Nitrogen. The choice of these 5 parameters was based on 3 factors: (1) Representativeness of different types of pollution; (2) On both highways, the existence of several samples with the pollutant; (3) concentrations above the maximum limit established in the decree-law (Fe case). This decree-law concerns wastewater effluents from wastewater treatment plants, being used as gauge for runoff waters, due to the non-existent legislation for these in Portugal. Then, a results table is presented for the 5 parameters selected, and for the road, the median of the concentration at the site, the maximum value recorded and the pollutant load were evaluated, resulting in that for both roads, the number of samples with values above.	It's considered that the amount of data studied in this paper is not sufficient to characterize all seasons of the year. However it's possible to conclude that in Portugal there are some key pollutants that need a special focus when dealing with runoff pollution: TSS, COD and Fe in road runoff, due to at least two of the following reasons: high mean concentration, high maximum concentrations and potential to first-flush occurrence. It's also possible to conclude that highways that are located in more arid areas (and consequently with longer "antecedent dry period") are more likely to produce acute impacts in short time periods, because of their potential to discharge higher concentrations of these pollutants.	3
[97]	Barbosa A., Telhado A., Caliço J., Fernandes J., Vieira J., Almeida L., Whitehead M., Ramísio P., Antunes P., Baguinho R. (2011) Guidelines for integrated road runoff pollution management in Portugal, G-Terra Project	Book chapter	2011	PT	Yes There is a brief resume of the study, a extensive description about monitoring and various types of pollutents	Yes There is a chapter dedicated to the multiparametric equation "PREQUALE 1.1"	Yes There is a chapter dedicated to the standards of protection of the receiving water body	Yes In the chapter dedicated to the evaluation of the impacts of road runoff pollution, and in the annexes, data of the pollutants are presented at each study site and for each sample.	No Since the document essentially represents a guide for the integrated management of road runoff, there is no description of the monitored sites. However, a table of the contents to be included in a monitoring report is presented, which contains the contents related to the characterization of the road and the drainage basin.	This document is of great importance as it develops a guide for the integrated management of road runoff. It is extremely useful so that the much acclaimed water framework directive can be fulfilled. The G-Terra project, in which this document focuses, presents in its content 5 different study cases, all of them in Portugal, two of which had already participated in previous studies, and only the data were updated. This guide has 3 main objectives: to evaluate the impact on the receiving environment; make a survey of data; selection of the most appropriate methods of runoff management. Here is also the presented the legal framework for Portugal and discharge recommendations, as well as the types of pollutants that may consist of a matrix of a runoff and the key pollutants. This document also presents a mathematical model "*PREQUALE* 1.1", a result of the recommendations for predicting concentrations in road runoff, based on a set of monitoring carried out on 6 Portuguese roads. Lastly, this guidelines document presents extensive chapters describing the processes of monitoring runoff water, monitoring methods, location to monitor, and equipment to be used, and methodology for analysing these results. Finally, a chapter is presented related to the control and treatment systems of runoff water, presenting several treatment systems with their pros and cons.	G-Terra project is a support guide for monitoring and integrated management using as a case study Portugal. This guide, in addition to describing chapter by chapter, all the steps for integrated management, also presents a numerical multiparameter model "PREQUALE 1.1", which can be used in any runoff, provided that the variables under study, comply with the values that are available in the document. By monitoring the 5 case studies, the G-Terra project allowed us to define which pollutants are essential to monitor during a study of runoff: Temperature, Conductivity, Turbidity, Total Hardness, Chemical Oxygen Demand, Biochemical Oxygen Demand, Total suspended solids, Zinc, Copper and Iron.	4
[98]	Furumai H., Aryal R., Nakajima A. (2002) *Profile analysis of polycyclic aromatic hydrocarbons and heavy metals in size fractionated highway dust and runoff samples*, 9th ICUD, International Conference on Urban Drainage, Global Solutions for Urban Drainage	Conference Proceeding	2002	EN	Yes It was made a methodological study where the pollutants from runoff pollution and from road dust, are caught and then studied.The key pollutants studied on this paper was Polycyclic aromatic hydrocarbons and heavy metals	No	No	YesBesides the presence of data in tables, there is many graphs where this data is studied	Runoff monitoring was conducted at a highway drainage system with an area of 8.4 ha in Winterthur, Switzerland.The study area, consisting of two sections of highways and a ramp area, has a total length of 3 km, with the average daily traffic density ranging from 25300 to 73700 vehicles / day.	This paper consists of monitoring the drainage system of a highway in Switzerland. Here the polycyclic aromatic hydrocarbons and the heavy metals fractionated in the dust of highway, but also in their runoff, were analysed. During the study, and after the monitoring process presented, it was verified that the samples with more suspended solids had in their constitution quite a lot of heavy metals and PAH's. These same samples with high contents of suspended solids presented particles of considerable diameter, above 106 µm, which, according to the study of the runoff flow, had great part of their flow, in the so called first flush occurrence. In addition to these conclusions, zinc, copper, lead and PAH concentrations were also found to be within the range of the literature. The last conclusion drawn, which is very useful for the PROPER project, is that ten times more heavy metals were found in the highway runoff than in dust.	Here, profiles of heavy metals and PAHs were studied in a runoff, comparing the profile of the runoff of a motorway and the dust of that highway, in order to compare the pollutants and their dimensions. The first conclusion is that in samples with more suspended solids, a greater amount of heavy metals and PAHs is verified. It is also verified that during a runoff, the largest particles are almost entirely in the first flush, and the remaining runoff is composed of very fine particles, and 65% of the particles in the runoff are fine particles. It is also verified that the concentration of heavy metals is ten times higher in the runoff of the highway than in the dust of the same. Finally, the author concluded that it was interesting to re-conduct the same study, and the dust analysis of the road would have to be done immediately before the monitoring of runoff water.	3
[99]	Bäckström M.; Nilsson U.; Håkansson K.; Allard B.; Karlsson S. (2003) *Speciation of heavy metals in road runoff and roadside total deposition*, Water, Air and Soil Pollution, 147, 343-366	Paper	2003	EN	Yes It was made a methodological study where the pollutants from runoff pollution and from road dust, are caught and then studied. The key pollutants studied on this paper was Polycyclic aromatic hydrocarbons and heavy metals	No	No	Yes Besides the presence of data in tables, there is many graphs where this data is studied	Sampling was performed at two sites (Svaneberg and Norsholm) in mid Sweden during one year. In the paper is presented the average annual daily traffic, speed limit, number of lanes, road construction year, pavement, de-icing usage, runoff treatment, annual mean precipitation, mean temperature (to January and July), soil, groundwater character, topography, relative elevation, road inclining, land use, nearest city and location. There is a very complete table with all information of the site	This study aims at the speciation of heavy metals in the runoff of two roads. Thus, the concentrations of cadmium, cobalt copper, lead and tungsten were evaluated on two Swedish roads for a period of one consecutive one. It is verified through this study that the pollutant load increases essentially during the winter period, one of the possible justifications being the greater use of the vehicle. In this study there is a distinct promise from the others, since the two routes under study have quite different construction years. One of them has more lanes than the other, but in addition, one was only built after the ban on the use of leaded petrol. Here, a chemical analysis of all the samples was carried out, to which is added the speciation that was made of them, with the aid of software.	After analysing the results, the study presents several conclusions: There was an increase in particulate lead and zinc in November and December, corresponding to higher car use, but also to the use of de-icing salts and studded tires; The de-icing salts do not contribute significantly to increased pollution on the roads; Studded tires according to the salts that contribute to an increasing wear of the sidewalks; Other interesting discoveries will be that cobalt and tungsten are excellent indicators of traffic and consequent pollution of the receiving environment because they are pollutants that are not abundant in the natural environment and that the variations are almost entirely indicative of the excess of traffic.	3
[100]	Westerlund C.; Viklander M. (2005) *Particles and associated metals in road runoff during snowmelt and rainfall*, Science of the Total Environment, 362, 143-156	Paper	2005	EN	Yes It was made a methodological study where the pollutants from runoff pollution and from road dust, are caught and then studied. The key pollutants studied on this paper was Polycyclic aromatic hydrocarbons and heavy metals	No	No	Yes Besides the presence of data in tables, there is many graphs where this data is studied	Yes There is a very complete table with all informations of the site	The study by Westerlund and Viklander aimed to verify the particulates and metals associated with road runoff during the snowmelt and rainfall. The study was carried out in Sweden, based on the comparison of concentrations and pollutant loads, different ranges (sizes), between the melt period and the runoff, comparing several events. In the investigation it is still analysed the capacity of transport of particles of different sizes during the melting period, during the period of rain and still between the two periods. The final objective of this paper is to analyse a relationship between the metals present in the samples and the particle sizes resulting from the methodological assays.	There are several conclusions to be drawn, some of which are already known in the current literature of this area of study, and another not so much. The first conclusion that can be drawn from the paper presented is that pollutant concentrations are much higher during snowmelt for all particle size ranges than during road runoff. Another conclusion drawn from the author's analysis is that during the snowmelt period there are eight times more particles per liter of runoff than during a period of rainfall. Another response found during the analysis is that, during the melt period, the runoff presents five times more particles than during runoff occurring during rainfall above 0 ° Celsius. Last, but not least, it was found that the particle size analysed was directly related to the concentration of heavy metals present in the samples.	2

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[101]	Stotz G. (1987) *Investigations of the properties of the surface water run-off from federal highways in the FRG,* Science of the Total Environment, 59, 329-337	Paper	1987	EN	Yes There is a small excerpt dedicated to the methods used and procedures	No	No	Yes	The study was performed in three federal highways with heavy traffic in the years from 1978 to 1981. The study was carried out in a total area of 28.82 ha, with the description of different types of pavement (concrete and asphalt), speed limit and traffic load (140100 vehicles / day in total) of the 3 sections monitored. Data on climatic conditions that are relevant are presented, such as total precipitation (mm), average monthly precipitation (mm) and range (mm) and long-term yearly average (mm).	Stotz in 1987 elaborated this paper with the intention to investigate the properties of surface water runoff on 3 highways in Germany. This study was carried out continuously between 1978 and 1981. Several pollutants were studied, analysing 850 samples, and the pollutants to which more emphasis was given were: heavy metals, mineral oil, chlorides, nitrogen, phosphorus and COD. One of Stotz's main objectives was also to demonstrate how drainage of runoff influenced the load and concentration of pollutants in the environment.	The three highways show not only different pavements but also different drainage areas and impermeable areas. The pollutant load of the samples depends on the drainage method used (large permeable ditches or impermeable systems that carry high flow rates); Use of de-icing salts on the highways or roads leads to greatly increase the content of chlorides on the road and consequently also the receiving environment. It was even estimated that the content of chlorides in the runoff waters after the use of these salts was about fifty to five hundred times higher than the level of chloride in the rains, in a yearly average. The concentration of PAHs in the runoff is about fifty to sixty times higher than the average that the German lakes present. It can also be concluded that only 14% of the PAHs are in the soluble phase, so that only with an efficient method of separation of solids, in the face of run-off, would lead to the removal of a large part of the PAHs.	2
[102]	Hallberg M., Renman G., Lundbom T. (2006) *Seasonal Variation of tem metal in highway runoff and their partiiton between dissolved and particulate matter*, Water Air Soil Pollution, 181, 183-191	Paper	2006	EN	Yes	No	No	Yes	Runoff data was collected from a section of the European highway system E4 in the central area of Stockholm, Sweden. This Section consists in a six lane road with an asphalt surface. The total traffic load varied between 4300 and 144600 vehicles during time of sampling, while the average speed varied between 52 and 83 km/h. The AADT at this highway section is 120000 and the speed limit is 70km/h. The runoff from this road surface (13,700 m2) and also additional insignificant volumes of drainage water from a road tunnel is by gravity transported through a sewer system to a treatment plant at Fredhäll for sedimentation. Data on climatic conditions that are of relevance in the study are presented, containing average temperature and precipitation.	In this study, Hallberg attempted to verify the seasonal variations of ten metals in highway runoff and their partition between dissolved matter and particles. The differentiation between the particulate and dissolved part is quite important in the process of water treatment, as well as the variations of its pollutant load. Here ten metals were studied, taking into account both their particulate and dissolved parts, during the winter and during the summer immediately following. During the monitoring, it was verified that the dissolved part was in its greater more representative in the winter than in the summer. Nevertheless the Fe was greater in the Summer than in the winter, and the Cu, Pb and Zn did not experienced significant alterations between stations . Concerning the concentrations of metals, it was found that for Al and Co the concentration was higher in winter, while the rest were higher in the summer. Finally, the author also performed a liner regression between the SS and the studied metals, verifying that in winter, the concentration of metals can be given by the concentration of SS.	The study revealed the following conclusions: (some of them already indicated in the resume) - In winter the pollutant load on metals is higher than in summer. - There is a good correlation between Al, Fe and SS concentrations. - One of the most important conclusions is that the correlation between the SS and the studied metals was higher than 0.95, except for the Cd, and the pollutant load could be verified by the SS.	3
[103]	Huber M., Helmreich B. (2016) *Stormwater Management: Calculation of Traffic Area Runoff Loads and Traffic Related Emissions, Water 2016, 8(7), 294*	Paper	2016	EN	Yes, focus on heavy metals. Review paper. Data from several literature references	No	No	Yes, it is a review paper with analysis of other studies. Only average values are available.	Several sites from literature survey	Metals such as antimony, cadmium, chromium, copper, lead, nickel, and zinc can be highly relevant pollutants in stormwater runoff from traffic areas because of their occurrence, toxicity, and non-degradability. Long-term measurements of their concentrations, the corresponding water volumes, the catchment areas, and the traffic volumes can be used to calculate specific emission loads and annual runoff loads that are necessary for mass balances. In the literature, the annual runoff loads are often specified by a distinct catchment area (*e.g.*, g/ha). These loads were summarized and discussed in this paper for all seven metals and three types of traffic areas (highways, parking lots, and roads; 45 sites). For example, the calculated median annual runoff loads of all sites are 355 g/ha for copper, 110 g/ha for lead (only data of the 21st century), and 1960 g/ha for zinc. In addition, historical trends, annual variations, and site-specific factors were evaluated for the runoff loads. For Germany, mass balances of traffic related emissions and annual heavy metal runoff loads from highways and total traffic areas were calculated. The influences on the mass fluxes of the heavy metal emissions and the runoff pollution were discussed. However, a statistical analysis of the annual traffic related metal fluxes, in particular for different traffic area categories and land uses, is currently not possible because of a lack of monitoring data.	Runoff loads of different traffic areas were summarized for highways, roads, and parking lots. In contrast to highways and roads, parking lots must be considered individually because of site-specific factors. The traffic related emissions in Germany were estimated for seven different sources (tire wear, brake lining wear, roadway abrasion, weights for tire balance, guardrails, lampposts/signs, and de-icing salts). Zn is mostly emitted by galvanized elements and tires, Cu and Pb by brakes, and Cd by de-icing salts. The calculated loads are comparable with the ones presented in other studies for most metals. However, a statistical analysis of traffic related metal mass fluxes is not currently possible because of a lack of monitoring data. Nevertheless, the estimation of the runoff loads and the emission loads for Germany stated that the vehicles, the road design, and the winter services emit heavy metals in large quantities (0.93 t/yr Cd, 935 t/yr Cu, 84.4 t/yr Pb, and 2094 t/yr Zn) and the runoff also contains high amounts of metal loads per year. Currently, the most relevant metals are Cu and Zn because the annual Pb loads have decreased significantly in the last few decades and traffic related Cd and Ni contribute only 5% and 11% of the total emissions in Germany, respectively. The loads of the other metals can also be detrimental for receiving waters and aquatic biota. In particular, for the highly toxic metals Cd and Sb. Thus, efforts should be intensified to reduce traffic related loads (both emissions and runoff) and subsequently to minimize their input into receiving waters and soils.	5