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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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
Task 1.1. Literature review on road runoff pollution on Europe
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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.](image_url)
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.

![Graph showing frequency of references per 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.

![Graph showing frequency of references per year]

Figure 3. Frequency of the references regarding the year of publication.
The various languages of the 103 publications are evaluated in Figure 4.

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.

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.
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.](image)

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

- Piguet P. (2007) Road runoff over the shoulder diffuse infiltration real-scale experimentation and optimization, PhD Thesis, EPFL, Lausanne, Switzerland

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 ($\text{NO}_3^-$), nitrites ($\text{NO}_2^-$), ammonium ($\text{NH}_4^+$), total Kjeldal nitrogen (TKN), total nitrogen (TN), phosphate ($\text{PO}_4^{3-}$) 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 (Cx)

As for PAH, Cx 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 Cx 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 catalyst 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)**

<table>
<thead>
<tr>
<th>Constituent</th>
<th>EMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>41 µg/L</td>
</tr>
<tr>
<td>Copper (dissolved)</td>
<td>20.58 µg/L</td>
</tr>
<tr>
<td>Zinc</td>
<td>140.3 µg/L</td>
</tr>
<tr>
<td>Zinc (dissolved)</td>
<td>57.49 µg/L</td>
</tr>
<tr>
<td>Lead</td>
<td>23.05 µg/L</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>0.72 µg/L</td>
</tr>
<tr>
<td>Benzo(b)fluoranthene</td>
<td>0.14 µg/L</td>
</tr>
<tr>
<td>Benzo(k)fluoranthene</td>
<td>0.09 µg/L</td>
</tr>
<tr>
<td>Benzo(a)pyrene</td>
<td>0.15 µg/L</td>
</tr>
<tr>
<td>Indeno(123)cdpyrene</td>
<td>0.11 µg/L</td>
</tr>
<tr>
<td>Benzo(ghi)perylene</td>
<td>0.08 µg/L</td>
</tr>
<tr>
<td>Chloride (de-icing salt)</td>
<td>258.43 mg/L</td>
</tr>
<tr>
<td>BOD</td>
<td>6.59 mg/L</td>
</tr>
<tr>
<td>TSS</td>
<td>114.58 mg/L</td>
</tr>
</tbody>
</table>
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 \(\text{PO}_4^{3-}\) 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.
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>
<thead>
<tr>
<th>Source</th>
<th>Substance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carburant, gasoline</td>
<td>Lead, nickel, zinc, soot, PAH, Cₙ, BTEX</td>
</tr>
<tr>
<td>Oils, lubricants and greases</td>
<td>Lead, zinc, nickel, PAH, Cₙ, BTEX, PCB</td>
</tr>
<tr>
<td>Exhaust gas</td>
<td>Brome, lead, nickel, PAH, Cₙ, BTEX, MTBE</td>
</tr>
<tr>
<td>Exhaust gas catalyser</td>
<td>Platinum, palladium, rhodium, PAH, Cₙ, BTEX, MTBE</td>
</tr>
<tr>
<td>Brake pad</td>
<td>Copper, chromium, nickel, manganese, lead, dirt</td>
</tr>
<tr>
<td>Tyres wearing</td>
<td>Rubber, soot, Sulphur, zinc oxide with cadmium and lead traces</td>
</tr>
<tr>
<td>Wearing course</td>
<td>Particles and colloids: Zinc, silicate, calcium, magnesium PAH</td>
</tr>
<tr>
<td>Concrete</td>
<td>Dirt</td>
</tr>
<tr>
<td>Asphalt</td>
<td>Dirt, PAH</td>
</tr>
<tr>
<td>Tar</td>
<td>Organic compounds, PAH</td>
</tr>
<tr>
<td>Marking paints</td>
<td>Rutile</td>
</tr>
<tr>
<td>Railing, signalization</td>
<td>Iron, zinc, chromium, nickel</td>
</tr>
<tr>
<td>Corrosion, wearing</td>
<td>Aluminium, copper, iron, cobalt, manganese</td>
</tr>
<tr>
<td>Maintenance services</td>
<td>Sodium, calcium, chlorine, sulphaye, herbicides, etc.</td>
</tr>
</tbody>
</table>
In the table, C₆, 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).

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorides (mg/L)</td>
<td>84.5</td>
<td>22.2</td>
<td>7.4</td>
<td>19.6</td>
<td>44.7</td>
<td>67.7</td>
<td>6.8</td>
<td>16.9</td>
<td>52.4</td>
<td>8.1</td>
<td>224.7</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>-</td>
<td>6.7</td>
<td>-</td>
<td>-</td>
<td>108.2</td>
<td>7.7</td>
<td>6.7</td>
<td>23.3</td>
<td>-</td>
<td>36.5</td>
<td></td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>-</td>
<td>81.9</td>
<td>-</td>
<td>-</td>
<td>83.0</td>
<td>109.1</td>
<td>22.2</td>
<td>70.2</td>
<td>38.3</td>
<td>-</td>
<td>195.9</td>
</tr>
<tr>
<td>Fe (mg/L)</td>
<td>0.724</td>
<td>0.350</td>
<td>0.333</td>
<td>0.353</td>
<td>1.482</td>
<td>2.746</td>
<td>0.105</td>
<td>0.224</td>
<td>1.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zn (mg/L)</td>
<td>0.159</td>
<td>0.127</td>
<td>0.208</td>
<td>0.346</td>
<td>0.205</td>
<td>0.134</td>
<td>0.214</td>
<td>0.177</td>
<td>0.16</td>
<td>0.308</td>
<td>0.076</td>
</tr>
<tr>
<td>Cu (mg/L)</td>
<td>0.034</td>
<td>0.020</td>
<td>0.033</td>
<td>0.008</td>
<td>0.014</td>
<td>0.072</td>
<td>0.027</td>
<td>0.009</td>
<td>0.03</td>
<td>0.024</td>
<td>0.032</td>
</tr>
<tr>
<td>Pb (mg/L)</td>
<td>0.012</td>
<td>0.003</td>
<td>0.004</td>
<td>0.002</td>
<td>0.005</td>
<td>0.044</td>
<td>0.006</td>
<td>-</td>
<td>0.02</td>
<td>0.012</td>
<td>0.009</td>
</tr>
</tbody>
</table>

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](image)

**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.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Pollutants</th>
<th>Name</th>
<th>Method</th>
<th>Input variables</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgins et al. (2007)</td>
<td>TSS</td>
<td>-</td>
<td>multiple linear regression</td>
<td>Duration of the storm, discharge volume, rainfall intensity, antecedent dry period and number of vehicles travelled in the ADP</td>
<td>Developed for Ireland</td>
</tr>
<tr>
<td>Kayhanian et al. (2007)</td>
<td>TSS, TDS, DOC, TOC, Cu, Pb, Ni, Zn and nutrients P, TK and No; NCu and Ni</td>
<td>-</td>
<td>multiple linear regression</td>
<td>total event rainfall (TER); cumulative seasonal rainfall (CSR); antecedent dry period (ADP); contributing drainage area (DA); and annual average daily traffic (AADT)</td>
<td>Established for California, USA</td>
</tr>
<tr>
<td>Barbosa et al. (2011)</td>
<td>TSS, Zn, Cu, Pb</td>
<td>PREEQALE</td>
<td>Multiparametric equation</td>
<td>A – drainage area in km²; I – Impervious percentage area (%); P – Mean precipitation height for a rainfall event with duration equal to the concentration time of the catchment (mm); P_a = Annual mean precipitation</td>
<td>Established for Portugal</td>
</tr>
<tr>
<td>Crabtree (2008)</td>
<td></td>
<td>HAWRAT (Highways Agency Water Risk Assessment Tool)</td>
<td>Spreadsheet</td>
<td>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</td>
<td>Blackbox spreadsheet (without concentration calculation) Established for the UK</td>
</tr>
<tr>
<td>Granato (2013)</td>
<td></td>
<td>SELDM (Stochastic Empirical Loading &amp; Dilution Model)</td>
<td>Software package</td>
<td>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.</td>
<td>Established for the USA</td>
</tr>
<tr>
<td>Gardiner et al. (2016)</td>
<td></td>
<td>RSS (road stormwater screening)</td>
<td>Spreadsheet</td>
<td>- Carriageways; - AADT; - Drainage; - Surface water channels</td>
<td>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.</td>
</tr>
</tbody>
</table>
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, Japan, 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.
References


CALTRANS (2003) Discharge Characterization Study Report, California Department of Transportation CTSW-RT-03-065.51.4


EIASERVIS (2004) Real concentrations of chloride ions in surface water from roads on 10 selected road sections in winter 2003/2004. EIA SERVIS s.r.o., Institute of Hydrobiology, Czech Academy of Sciences, České Budějovice and Faculty of Biology, České Budějovice, Directorate of Roads and Motorways of the Czech Republic


Piguet P. (2007) Road runoff over the shoulder diffuse infiltration real-scale experimentation and optimization, PhD Thesis, EPFL, Lausanne, Switzerland


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


APPENDIX 1 – List and contents of literature references

ID | Complete Reference | Type | Year | Country | Monitoring study? | Brief reference of the study & key pollutants | Modelling study? | Brief reference of the study & modelling tool | Relevancy of the receiving water body? | Available data? | Characteristics of the site | Resume | Conclusions |
---|---|---|---|---|---|---|---|---|---|---|---|---|---|
3 | Béchet B., Durin B., Lognot M., Le Clézio P. (2006) Colloidal speciation of heavy metals in runoff and interstitial waters of a retention/infiltration pond in the Loire Valley, France, Ecological Engineering, 28(2), 159-169 | Paper | 2006 | EN | Yes | Yes | Yes | No | Yes partially | Yes, there are various tables in the Paper. | As above | | |

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 1980 an average daily total traffic of 90,000 vehicles. The bridge is 1500 m long and 14.6 m wide. Camargues consist of three lanes in each direction, separated by a central reservation and the pavement consists of a conventional asphalt surface. The run-off waters of the 1900 m² contribution area are collected in gulleys and flowed in aluminum 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 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 per-urban highway experimental site was chosen to sample runoff waters from a bridge with a heavy traffic of 80,000 vehicles per day, during two years. The objective was to study the distribution of selected trace metals (Cd, Cu, Cr, 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.

The three following tables summarise the main findings of the study. Data collection on runoff waters and waters in the retention-infiltration pond at Cheviré was carried out over about one year. The important finding 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 recently removal of lead from fuel, the measured concentrations of Pb in road runoff waters were not markedly different from literature values. Regarding the fractionation of heavy metals in dissolved and colloidal fractions, we conclude that Pb and Cd are present in the different fractions from 0.22 µm to 2 µm, whereas Zn, Cu, Ni and Cr are present in the different fractions from 2 µm to 20 µm. 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 Zn, 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 study is devoted to the evaluation of the pollutant content in first flush runoff waters emerging 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 are also contaminated with very high concentrations of Pb, Cr and Cd, which are known to associate with particles, were present entirely in the 0-10 µm-size particles of runoff waters. Zn and Ni were distributed mostly in the particulate fractions but dissolved with dissolved (<0.2 µm) and colloidal fractions up to 30%. The distribution of Cu is quite equal to Zn and Ni, with up to 70% of Cu colloidal. 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 and Ni 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 in metallic oxy-hydroxides and Aluminous particles. This study revealed 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 runoffs.
<table>
<thead>
<tr>
<th>ID</th>
<th>Type</th>
<th>Country</th>
<th>Year</th>
<th>Monitoring study/ Brief resume of the study &amp; key pollutants</th>
<th>Modelling study/ Brief resume of the modelling tool</th>
<th>Availability data?</th>
<th>Characteristics of the site</th>
<th>Residue</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Report</td>
<td>FR</td>
<td>2001</td>
<td>Yes, pH, EC, TSS, chemical oxygen demand, Kjeldahl nitrogen, chlorine and sulfates, metals, total hydrocarbons, PAHs.</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>The campaign carried out between March 1996 and February 1998 on the A11 highway showed that the total HC content of runoff water was quite high (between 16 and 4.2 mg/L), PAH concentrations were low (&lt; 1.2 mg/L), only fluorine and benzo[g,h,i]perylene were above the detection limit. For trace metals, the most important concentrations were for Pd and Cu and Cd concentration were generally quite high. Pd and Cd 2 concentrations were higher in winter, probably due to the use of die-casting agents. pH always remained close to 7. EC was strongly dependent on the season (max in summer, 0.17 mg/L in winter, as TSS (mean TSS content of 71 mg/L), but higher in winter in chloride and sulfates in concentrations (respectively equal to 1015 mg/L and 35 mg/L during the winter period). Nitrogen concentrations were consistently low.</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Report</td>
<td>FR</td>
<td>2007</td>
<td>Yes</td>
<td>No No No Yes Yes Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>The initial pavement (conventional asphalt) was renovated with a 30 mm thick layer of porous asphalt (type on an impervious surface during the 1996 summer. Second experimental campaign after the renovation, between June and November 1997.</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Report</td>
<td>FR</td>
<td>2001</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>The initial pavement (conventional asphalt) was renovated with a 30 mm thick layer of porous asphalt (type on an impervious surface during the 1996 summer. Second experimental campaign after the renovation, between June and November 1997.</td>
<td>No</td>
<td>The result is at odds with the campaigns carried out on the A11 highway. Runoff waters have also been sampled (pH, EC, chemical oxygen demand, TSS and trace metals) in two sites located near the Wancourt rest area, on the A11 highway.</td>
</tr>
<tr>
<td>4</td>
<td>Paper</td>
<td>EN</td>
<td>2012</td>
<td>Yes No No Yes Yes Yes</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>No specific site. Review based on different peer-reviewed papers. There was no definitive high frequency runoff characterization studies performed in Europe. North America, East Asia and Australia / New Zealand.</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>Paper</td>
<td>EN</td>
<td>2012</td>
<td>No No No Yes Yes Yes</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>The study is devoted to the performance of grass swales for treating highway runoff. Grass swales are known to provide water quality enhancement services.</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Paper</td>
<td>EN</td>
<td>2002</td>
<td>No No No Yes Yes Yes</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>No specific site. Review based on different peer-reviewed papers. There was no definitive high frequency runoff characterization studies performed in Europe. North America, East Asia and Australia / New Zealand.</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>Paper</td>
<td>EN</td>
<td>2012</td>
<td>Yes No No Yes Yes Yes</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>No specific site. Review based on different peer-reviewed papers. There was no definitive high frequency runoff characterization studies performed in Europe. North America, East Asia and Australia / New Zealand.</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>Paper</td>
<td>EN</td>
<td>2007</td>
<td>Yes No No Yes Yes Yes</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>The road (road 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 it is not affected by the overlying layers. The water quality parameters were TSS, total chlorides, TKN, total phosphorus, chlorides, lead, copper and cadmium.</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>Paper</td>
<td>EN</td>
<td>2007</td>
<td>Yes No No Yes Yes Yes</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>The road (road 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 it is not affected by the overlying layers. The water quality parameters were TSS, total chlorides, TKN, total phosphorus, chlorides, lead, copper and cadmium.</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Paper</td>
<td>FR</td>
<td>2007</td>
<td>No No No Yes Yes Yes</td>
<td>No No No Yes Yes Yes</td>
<td>No</td>
<td>Yes</td>
<td>This new method of runoff management has been designed to be applied in a real-world experiment underway in Switzerland. This concept is based on the simulation of the road runoff in the infiltration slope edging the road shoulder.</td>
<td>No</td>
</tr>
<tr>
<td>ID</td>
<td>Complete Reference</td>
<td>Type</td>
<td>Year</td>
<td>Country</td>
<td>County</td>
<td>Monitoring study/ Brief resume of the study &amp; key pollutants</td>
<td>Modelling study/ Brief resume of the study &amp; modelling tool</td>
<td>Concurrency of the receiving water body</td>
<td>Available data?</td>
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<tr>
<td>9</td>
<td>Helofyteninfiltratiesystemen</td>
<td>Report</td>
<td>2005</td>
<td>NL</td>
<td>No</td>
<td>Monitoring study on the efficacy of a helophyte filter next to the highway A1 in the Netherlands. It includes information on concentrations of PAHs (higher loads during a rain event after a dry period), metals (Cu and Zn) and PAH in runoff water and in infiltrating/influent water of the helophyte filter and influent/effluent of drains.</td>
<td>The The monitoring site is located at highway A1 in the Netherlands, near 1 Goo. The road consists of porous asphalt, which was cleaned 4 times during the monitoring period.</td>
<td>No additional modelling.</td>
<td>No</td>
</tr>
<tr>
<td>10</td>
<td>de Boeij, J., Vergouwen, A., Schipper (2003) Run-off en verwaging Fluvoide wegen</td>
<td>Report</td>
<td>2002</td>
<td>NL</td>
<td>No</td>
<td>Literature review on road run-off on secondary roads (with data on concentrations from several older monitoring studies)</td>
<td>No modelling</td>
<td>No</td>
<td>Yes. From the monitoring studies (concentrations in run-off, ground water and soil)</td>
</tr>
<tr>
<td>11</td>
<td>van den Berg, G.A., Luningeman, H.D., Veenhoven, H., 2009. Emissie van afvalstoffen door run-off en verwaging Fluvoide wegen.</td>
<td>Report</td>
<td>2010</td>
<td>NL</td>
<td>No</td>
<td>Yes. 5 metals and 16 PAHs were measured at the discharge and in the soil in sedimentation ponds.</td>
<td>No</td>
<td>No, Only in comparison with permits</td>
<td>Concentrations at the discharge of a sedimentation pond and of the water source</td>
</tr>
</tbody>
</table>


M., Marvanová S., Huzlík. Stabilization and gradual reduction of environmental impact of contaminated from the highway was determined and collected in the retention ponds using two different sampling methods. The sampling locations of Rozvadov and Helmarova Huf are located on the D5 highway near 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 highways. Runoff waters are detained here, suspended particles are settled and wash flow to the recipient where they are diluted.

The research work focused on the runoff water contamination study of highway D1. Runoff settling reservoirs (RSRs), which are part of the D1 drainage system, were observed. These are lakes into which collecting sewers are discharged to drain 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 reservoir, the organic matter is partially recovered due to the action of microorganisms. Water from RSRs are representative of the contamination of transport activities.

The 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 some 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 filters 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 oil in the inflow water, the results are washed out from the filter and concentration of mineral oils are higher in the outflow water.

The study was supported by the Czech Ministry of Transport as research project MD CR 02. It determined and collected in the retention ponds from highways and motorway receiving collectors, small settlements.

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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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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<table>
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<th>ID</th>
<th>Complete Reference</th>
<th>Type</th>
<th>Year</th>
<th>County</th>
<th>Project</th>
<th>Monitoring study/ Brief description of the study</th>
<th>Modelling strategy/ Brief resume of the study</th>
<th>Model/ Tool</th>
<th>Conformity of the model to the water body?</th>
<th>Available data?</th>
<th>Characteristics of the site</th>
<th>Resume</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>04</td>
<td>Beránková D., Huzlík J., Kupec J., Přešek, J., Prax P. (2008)</td>
<td>EN</td>
<td>2008</td>
<td>N</td>
<td>MfP</td>
<td>Monitoring project of the Ministry of Transport of the Czech Republic. Basic chemical parameters were determined in water samples and in the rainwater, in which chloride concentration was also determined.</td>
<td>No</td>
<td></td>
<td>Yes, data is available</td>
<td></td>
<td>Chloride concentration monitoring was carried out in the period of 2005 – 2007 on the highway D1 Prague-Bílovice between 61.5 and 81.5 km.</td>
<td>The results show that the surface runoff on the monitored area currently contains less pollution, especially metals. The amount of chloride monitored pollutants was higher in the surface runoff on transport infrastructure samples than in the rainwater samples, which presents a certain impact of traffic on the runoff water quality. The contamination of outflows from the monitored retention facilities has been in the same range of values since 2008. The retention facilities have been showing high elimination of monitored pollutants, but as was shown in the case of CTS-C40 substances, an appropriate management is necessary (e.g. sediment disposal) to prevent secondary contamination of outflow water.</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>České Budějovice</td>
<td>EN</td>
<td>2014</td>
<td>N</td>
<td>Vodňany</td>
<td>Runoff water monitoring on urban roads and car parkings within the project of the Research Centre of Transport Sciences, vol. 7</td>
<td>No</td>
<td></td>
<td>Yes, data is available</td>
<td></td>
<td>The paper presents the final results of the project dealing with the quantity and quality of highway runoff. Field investigation was carried out during the period of 2005 - 2007 on some stretches of D1 highway Prague - Bílovice. 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 Spirodeles polynemus misconducts, was confirmed through ecotoxicity testing. The measurement of precipitation and runoff has also brought findings about the variability of runoff coefficient in this both up transport area.</td>
<td></td>
<td>The negative impact of runoff from highways on the recipients and water bodies also enhances a certain amount of priority dangerous substances as specified by EU. High concentrations of chloride from road maintenance works, as well as metals, were demonstrated by testing on algae. During intensive rainfall small amount of water is flushed from the roadside solid runoffs and transported into the river basin. Similarly, as in other European states, it seems to be necessary to control and prevent this potential strain of pollution along the highways and to do the best management practices and to project and implement protective measures against it.</td>
</tr>
<tr>
<td>02</td>
<td>Beránková D., Kriška M., Kupec J., Přešek, J., Prax P. (2004)</td>
<td>CZ</td>
<td>2004</td>
<td>N</td>
<td>Vodňany</td>
<td>An ecological study dealing with the influence of road sections on the contamination of surface water by chloride. Chloride concentration monitoring was carried out on 10 selected road sections in winter 2003/04.</td>
<td>No</td>
<td></td>
<td>Yes, but limited</td>
<td></td>
<td>The concentration of chloride ions was monitored on ten selected sections of the road / 1 20 České Budějovice - Vodňany and 2 20 České Budějovice - Zaběnice. It was placed at 100 m distance from the road. Chloride concentration monitoring was carried out in the period between December 2005 and December 2006. Significant scaling was monitored on the basis of chloride content in the water. In winter 2005/2006, the impact of chloride concentrations in the roadway on the monitoring sites was confirmed.</td>
<td></td>
<td>The results show that chemical maintenance of the roads has resulted in a statistically significant increase in the concentration of chloride ions in surface runoff water. This increase in the concentration of chloride ions in the streams and rivers is caused by the use of sodium chloride as a deicer (i) an increase of 2.9 - 46.7 %. Only in one locality the average increase in chloride concentration in the streams and rivers (i.e. Českomoravská) was confirmed. This is probably 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 in 77 % of the monitored times, chloride applied on the road do not flow through the cross-flow (recipient), but they are absorbed by the soil and are gradually get into the surface water. The chloride concentrations in the water samples were determined in the period of March 2004 and 114 pairs of samples in the period April - September 2004.</td>
</tr>
<tr>
<td>27</td>
<td>Vlčáková, V., Šípková K., Klíma V., Jungrer, A. (2007)</td>
<td>CZ</td>
<td>2007</td>
<td>CHK</td>
<td>Vodňany</td>
<td>An ecological study dealing with the influence of road sections on the contamination of surface water by chloride. Chloride concentration monitoring was carried out in the period between December 2005 and December 2006. The main objective of the study was to evaluate the real direct effects of chemical road maintenance in the winter season on the catchments (runoff inflow to the stream or river) and the pollution of vegetation.</td>
<td>No</td>
<td></td>
<td>Yes, data is available</td>
<td></td>
<td>Chloride concentration monitoring was carried out in the period between December 2005 and December 2006. Differences in concentrations above and below the highway are monitored. In winter 2005/2006, the impact of chloride concentrations in the roadway on the monitoring sites was confirmed.</td>
<td></td>
<td>The results show that chemical maintenance of the roads has resulted in a statistically significant increase in the concentration of chloride ions in surface runoff water. This increase in the concentration of chloride ions in the streams and rivers is caused by the use of sodium chloride as a deicer (i) an increase of 2.9 - 46.7 %. Only in one locality the average increase in chloride concentration in the streams and rivers (i.e. Českomoravská) was confirmed. This is probably 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 in 77 % of the monitored times, chloride applied on the road do not flow through the cross-flow (recipient), but they are absorbed by the soil and are gradually get into the surface water. The chloride concentrations in the water samples were determined in the period of March 2004 and 114 pairs of samples in the period April - September 2004.</td>
</tr>
<tr>
<td>03</td>
<td>Huzlík J., Klíma V., Jungrer, A. (2004)</td>
<td>CZ</td>
<td>2004</td>
<td>CHK</td>
<td>Vodňany</td>
<td>The methodology was used in the framework of the project Research of the seasonal chloride concentrations in road catchments (2003-2004). Chloride content in the rainwater was determined.</td>
<td>No</td>
<td></td>
<td>No</td>
<td></td>
<td>Chloride concentration monitoring was carried out in the period between December 2005 and December 2006. Differences in concentrations above and below the road were monitored.</td>
<td></td>
<td>The methodology defines a monitoring network that is composed of sampling sites. These are determined using eight basic parameters that describe each section of the road/corridor including its surroundings. These parameters include characterization of road (or road network) such as width, drainage system, type of pavement, the type of traffic and flow, the type of environment covered by the road (or road network).</td>
</tr>
<tr>
<td>ID</td>
<td>Complete Reference</td>
<td>Year</td>
<td>Country</td>
<td>Monitoring study? Brief resume of the study &amp; key pollutants</td>
<td>Modelling study? Brief resume of the study &amp; modelling tool.</td>
<td>Controllability of the receiving water body?</td>
<td>Available data?</td>
<td>Characteristics of the site</td>
<td>Resume</td>
<td>Conclusions</td>
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<tr>
<td>[39]</td>
<td>Barnett M., Malina F., Chartier R., Ward G. (1995) Characterization of highway runoff in the Austin, Texas area. Technical report CRWRI-263, University of Texas at Austin</td>
<td>1995</td>
<td>EN</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>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 TVSS); E. coli; Biocatalytic Oxygen Demand (BOD5); Chemical Oxygen Demand (COD); Total Organic Carbon (TOC); oil and grease (O&amp;G); nutrients (inorganic and total phosphorus), heavy metals (iron, lead, cadmium, nickel, zinc, and copper), and bacteria (total coliform, fecal coliform, and faecal streptococcus); data presented as EM's and median concentrations and estimated annual pollutant loadings (high).</td>
<td>Water quality of highway runoff in the Austin, Texas area was determined by monitoring runoff at three locations on MoPac, which represented different daily vehicle use patterns, surrounding land uses, and highway drainage system types. 5th sheet = high traffic site (60,000 vehicles per day). Conimic Ht = low traffic site (5700 vehicles per day). Runoff flow rates were measured and samples were collected automatically during rainfall events (doesn't state how many). Higher 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 point source pollutants, are relatively a minor proportion 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 flash 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 monitoring 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 pollutant concentrations for individual storm events should be assumed.</td>
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<td>[40]</td>
<td>CALTRANS (2003) Discharge Characterization Study Report, California Department of Transportation CTSW-RT-03-065.51-A</td>
<td>2003</td>
<td>EN</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>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. ADT 1800-259000; catchment = 0.08-5.9 ha.</td>
<td>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 ADAT, 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. Summaries data on: Relationships Between Runoff Quality and Other Factors, Event and Seasonal &quot;First Flush&quot; 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 WD objectives, Correlation Between Constituents and Percentage of Metals in the Particulate Fraction.</td>
<td>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. ADAT 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 ADAT. 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.</td>
<td>4</td>
<td></td>
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<td>[41]</td>
<td>Higgins N. (2007) Analysis of Highway Runoff in Ireland. Trinity College Department of Civil, Structural and Environmental Engineering, 2007. 443 pp.</td>
<td>2007</td>
<td>IE</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Multiple regression analysis of flow and pollutant concentrations/loads with storm event characteristics. Sediment, invertebrate and fish impact assessment of flowsurface water quality.</td>
<td>Conventional storm flow model monitored and investigated 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. It has been observed that tidal flow and rainfall volume contribute quite high pollutant concentrations (although little MTBE found) to surface washoff with filter drain ineffective 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 indicator contaminant.</td>
<td>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 GS&gt;Pav/Cruden + HMs, TSS and PO4 frequently exceeding EU EQS and also exhibiting strong first flushes.</td>
<td>3</td>
<td></td>
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<tr>
<td>[42]</td>
<td>Higgins N., Johnson P., Dore M., Buen M., Dezza M. (2008) Highway Runoff in Ireland and Management with a French Drain System. Proce.11th Int. Conf. Urban Drainage, Edinburgh, Scotland</td>
<td>2008</td>
<td>EN</td>
<td>No</td>
<td>as above</td>
<td>as above</td>
<td>as above</td>
<td>as above</td>
<td>Water quality of highway runoff in the Austin, Texas area was determined by monitoring runoff at three locations on MoPac, which represented different daily vehicle use patterns, surrounding land uses, and highway drainage system types. 5th sheet = high traffic site (60,000 vehicles per day). Conimic Ht = low traffic site (5700 vehicles per day). Runoff flow rates were measured and samples were collected automatically during rainfall events (doesn't state how many). Higher 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 point source pollutants, are relatively a minor proportion 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 flash 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 monitoring 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 pollutant concentrations for individual storm events should be assumed.</td>
<td>3</td>
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<tr>
<td>[43]</td>
<td>Higgins N., Johnson P., Quinn M., Dezza M., Higgins N., Bradley C., Burns S. (2006) Impact Assessment of Highway Drainage on Surface Water Quality. Report 2006-M-13-02, Environment Protection Agency (EPA), Dublin, Ireland</td>
<td>2006</td>
<td>IE</td>
<td>No</td>
<td>as above</td>
<td>as above</td>
<td>as above</td>
<td>as above</td>
<td>Multiple regression analysis of flow and pollutant concentrations/loads with storm event characteristics. Sediment, invertebrate and fish impact assessment of flowsurface water quality.</td>
<td>Conventional storm flow model monitored and investigated 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. It has been observed that tidal flow and rainfall volume contribute quite high pollutant concentrations (although little MTBE found) to surface washoff with filter drain ineffective 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 indicator contaminant.</td>
<td>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 GS&gt;Pav/Cruden + HMs, TSS and PO4 frequently exceeding EU EQS and also exhibiting strong first flushes.</td>
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</tbody>
</table>
metal content of motorway runoff waters from a major detention ponds along the Environment Journal, 20, (1992)

Comparison of the heavy pollutants in the selected pollutants in the M25 motorway (1:45 pm) contained 90% of the inorganic Pb, 70% of the Cu and 56% of the Cd and the characteristic-metal phase concentrations were identified by the dissolved sediments. A significant correlation was found between the level of the oxidative 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 prediction of pollutant concentrations in the runoffs to be made from the discharge rate and the length of the ADP. Calculation shows that Pb, Cd and Pb and 3% of the PAs emitted by vehicles in the high discharge drainage waters.


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 a combined system of need of dewatering and dewatering material is used. Removal efficiencies of heavy metals within the biotreatment pond are higher than those removal efficiencies in upland detention ponds. The Surrey site is much better maintained than the M25 site as it is a part of a recreational area and is subject to regular maintenance. However, removal of particulate material through the attainment of a long residence time from stormwater runoff to receiving watercourse will greatly enhance the removal efficiency of heavy metals in stormwater from the biotreatment facility.


The Concentration 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 pm) contained 90% of the inorganic Pb, 70% of the Cu and 56% of the Cd and the characteristic-metal phase concentrations were identified by the dissolved sediments. A significant correlation was found between the level of the oxidative 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 prediction of pollutant concentrations in the runoffs to be made from the discharge rate and the length of the ADP. Calculation shows that Pb, Cd and Pb and 3% of the PAs emitted by vehicles in the high discharge drainage waters.


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Monitoring of suspended solids, dissolved and particulate phases of Pb, Cd and Cu, dissolved total organic Pb and total particulate Cu, with full rainfall listings at 1 min resolution. The section has a longitudinal slope of 1.3%, cross-sectional slopes of 1.5% and 3% for the carriageway and hard shoulder, respectively, an impervious drained area of 551570 and a permeable area of 302210. Schematic of sampling site and sample collection details provided. The period of study was 13 April 1986-11 April 1987, the daily average traffic flow was 32,000 vehicles and 1560 diesel powered vehicles. A total of 13 different storms and seven periods of low flow were intensively sampled.


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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 pollutants (Cu and Zn) have been selected for study. One of the main reasons for this choice is that Cu 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 loadings as regards lead appear lower than in previous studies because of the increasing number of vehicles using unleaded gasoline. The study conducted on the sources of pollution and the major pollutants (Cu, Zn) released by the traffic has been used to assess a mass balance with respect to pollutant loadings removed by runoff water. The major source of the lead concentration may disperse in the atmosphere, whereas cadmium sources may be ill-identified or underestimated.


The dynamic washoff behaviour of total SS, fractional SS and their particle associated PAHs. The results are compared for four rainfall events. The washoff behaviour, both in time and intensity, was significantly different between the two types of pavement described. The release of a certain fraction of PAHs from the asphalt by a porous asphalt are compared. Statistical tests have been used to evaluate the difference of the washoff mechanisms. The difference in the washoff behaviour between the two types of pavement is highlighted. This is attributed to the different transport mechanisms involved in the washoff process acting on the porous and conventional asphalt pavement. This study also shows the probable impact of the type of pavement on the potential impact on the environment.

The runoff water from highways is nearly neutral with low levels of nutrients in runoff. Hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and metals are the dominant pollutants. The runoff water from motorways is discoloured, with generally a brown to black appearance, due to the presence of various organic and inorganic pollutants. These pollutants are mainly from vehicles, including road dust, and from road-surface treatments. The runoff water from motorways is also relatively heavy metal polluted, with concentrations of Zn, Pb and Cu higher than at other types of site such as urban sites.

Pollutants in contrast to the low levels of nutrients in runoff. Highway runoff quality 1 year investigation. Oil & grease, SS and heavy metals are the dominant pollutants. The runoff water from motorways is discoloured, with generally a brown to black appearance, due to the presence of various organic and inorganic pollutants. These pollutants are mainly from vehicles, including road dust, and from road-surface treatments. The runoff water from motorways is also relatively heavy metal polluted, with concentrations of Zn, Pb and Cu higher than at other types of site such as urban sites.
ID  Complete Reference  Type  Year  Country  Monitoring study/ Brief resume of the study & key pollutants  Modelling study/ Brief resume of the study & key modelling tool  Concurrency of the receiving water body?  Available data?  Characteristics of the site  Resume  Conclusions


2016  Paper  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 (pavement 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 (HH); and HWY with an AADT of <30,000 (HL). Unfortunately highway sites are not identified and details are not tabulated.

- 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 (pavement 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 summarised. 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 galvanised structures and crutches of car tires. Rubbers 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.


2010  Paper  Review Paper covering heavy metals, PAHs, VOCs, MTBE, herbicides and SS in highway runoff.

- 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, VOCs), vehicle emissions, atmospheric deposition. UTC (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 influencing storm characteristics, road site conditions, ambient conditions and environmental attributes are assumed to have simultaneous and sometimes contradictory 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 modeling or other machine-learning techniques may be able to overcome the difficulties of dealing with numerous variables and vast variability.


2005  Conference Proceeding  Summary of studies presented above

- Highway surface runoff discharges may contain pollutants that have accumulated in 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.

- The results have been used to identify ranges of pollutant concentrations in highway runoff, relationships between runoff concentrations 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 characterize pollutants in highway runoff, and the measured pollutant removal efficiency of a range of drainage system types.


2007  Conference Proceeding  Summary of studies presented above

- As above

- The results have been used to identify ranges of pollutant concentrations in highway runoff, relationships between runoff concentrations 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 characterize pollutants in highway runoff, and the measured pollutant removal efficiency of a range of drainage system types.


2008  Conference Proceeding  Summary of studies presented above

- As above

- The results have been used to identify ranges of pollutant concentrations in highway runoff, relationships between runoff concentrations 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 characterize pollutants in highway runoff, and the measured pollutant removal efficiency of a range of drainage system types.


2008  Conference Proceeding  Summary of studies presented above

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<table>
<thead>
<tr>
<th>ID</th>
<th>Complete Reference</th>
<th>Type</th>
<th>Year</th>
<th>County</th>
<th>Characteristics of the site</th>
<th>Resume</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>Mayer T., Rochford Q., Marsalek J., Parrott J., Servis M., Baker M., McInnis A., Jukovic A., Scott I. (2011). Environment characterisation of surface runoff from three highway sites in Southern Ontario.</td>
<td>Paper</td>
<td>2011</td>
<td>EN</td>
<td>Monitoring study of road drainage from heavily trafficked highway bridge deck outside Burlington, Ontario, Canada. Principal pollutant studied was chlorides from de-icors, but also included TSS, HMs and PAHs. Highest concentrations and loadings associated with TSS and soluble fractions of runoff.</td>
<td>Study focused 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-month period with the principal effort focused on runoff chloride concentrations associated with winter de-icing operations. The monitoring 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 woodchips for control of HMs.</td>
<td>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 volume/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 19315 mg/L. Traffic intensity, highway condition and age as well as seasonal conditions. Companion Paper focuses on toxicity assessment of receiving water course impacts and vulnerability.</td>
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<tr>
<td>54</td>
<td>Trenouth W., Ghanebaghi B., Penes N. (2015). Road salt application planning tool for winter de-icing operations. Journal of Hydrology, 524, 401-410</td>
<td>Paper</td>
<td>2015</td>
<td>EN</td>
<td>as above</td>
<td>as above</td>
<td>as above</td>
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<td>56</td>
<td>R&amp;D Technical Report P2: 038TR6. A417. River Fosse-Site Report. ISBN 1844322016. October 2003. Environment Agency, Swindon, Wiltshire, UK.</td>
<td>Report</td>
<td>2003</td>
<td>EN</td>
<td>Correlation graphs for storm event relationships; rainfall volume, runoff intensity, duration, AIC and traffic volumes against individual pollutant conc and loadings. YES. Biological sample surveys and sediment analysis. YES and available on CD-ROM.</td>
<td>0 monitored non-rural highway sites in Berkshire (all more than 5 years old) composed of asphalt/pavement asphalt and heavily trafficked (&gt;5000 ADT) with 14% - 16% 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.</td>
<td>Depth and flow 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 inflow conditions. In addition, treatment efficiency and biological/ecological impact assessment investigated for the receiving watercourse. For rainfall events at 1 minute intervals for 10 storm events over a 13 month monitoring period are Reported as well as upstream/downstream in the receiving water course. 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 decreases 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 flow intensities and high flows during summer months.</td>
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Monitoring and modeling the performance of a wet 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 negligible. The two snowmelt events accounted for one third of the annual pollutant load, whereas a substantial part of the annual pollutant budget. 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. Hence, neither 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.


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 pond 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 additional nutrients may contribute to the runoff during winter.


Monitoring of one highway pond in Norway. No

No

Yes

One full year of highway runoff measurement (inlet to a pond)

A wet pond in 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 pond 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 additional nutrients may contribute to the runoff during winter.

Trivedi R., Ummal M., Bhattacharya J. (2008)


Trivedi R., Ummal M., Bhattacharya J. (2008)

Setting up of stormwater management ponds in India – survey of the operational status of 25 detention ponds across India. No

No

Yes

Yes

No

Yes

Yes

No

Yes

No

Yes

No

Yes

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Yes

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Yes

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No

Yes

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Yes

No

Yes

No

Yes

No

Yes

No

Yes

No

Yes

No

Yes

No

Yes
The Danish Road Directorate wishes to examine the findings of glyphosate and AMPA.

With these simulation results and field observations from Holttjern, the exposure of glyphosate and AMPA under the road barrier (121.1 ng/g of glyphosate and 423 ng/g of AMPA) was simulated. For AMPA the highest concentration was found at the inlet and outlet. For AMPA the highest concentration was found at the inlet and outlet.

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 administered 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 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.

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 regulatory purposes and environmental hazard. The most important prioritized compounds were MTBE, benzene, hexachloroethane, hyaline, medium chain paraffins, tetra- and pentabromobuykes, 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.
<table>
<thead>
<tr>
<th>ID</th>
<th>Complete Reference</th>
<th>Type</th>
<th>Year</th>
<th>Country</th>
<th>Monitoring study/ Brief resume of the study &amp; key pollutants</th>
<th>Modelling study/ Brief resume of the study &amp; modelling tool.</th>
<th>Conclusiveness of the receiving water body?</th>
<th>Available data?</th>
<th>Characteristics of the site</th>
<th>Residue</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>Klemen Karanfil Pavli</td>
<td>Paper</td>
<td>2014</td>
<td>NO</td>
<td>Monitoring of stormwater (pond sediment concentrations (metals, carbohydrates))</td>
<td>2x2 lanes and high traffic between 40.000 - 60.000 ADT</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not present</td>
</tr>
<tr>
<td>71</td>
<td>Hans-Jörg Lutz (2017)</td>
<td>Report</td>
<td>2017</td>
<td>GE</td>
<td>Monitoring highway runoff discharges (metals, PAH)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Not present</td>
</tr>
<tr>
<td>73</td>
<td>Kogovšek J. (2007)</td>
<td>Book chapter</td>
<td>2007</td>
<td>SI</td>
<td>Study summarised 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 lane with lanes for slow vehicles on higher slopes. ADT is up to 50,000</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>74</td>
<td>Kogovšek J. (2011)</td>
<td>Book chapter</td>
<td>2011</td>
<td>SI</td>
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<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**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 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 sediment contains toxic levels of metals and PAH. The concentrations of metals and PAHs in the sediment exceed the limits for use as fertilizer and for use as a building material. The results of the chemical analysis of the sediments indicate that the sediments from the wet sedimentation ponds are not suitable for use as fertilizer or for use as a building material.

**Road pollution.** 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 Kariška, Vinkovci and Frastikovci, and partly Strmolnagradnica, 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 substance concentrations exceed the environmental quality limits for use as fertilizer and for use as a building material. The results of the chemical analysis of the sediments indicate that the sediments from the stormwater ponds are not suitable for use as fertilizer or for use as a building material.

**Pollution of the Underground Karst.** The Kras region of Slovenia is the most valuable karstic area in the world, representing more than 1 m. Highways crossing karstic area 2x2 lane with lanes for slow vehicles on higher slopes. ADT is up to 50,000. The pollution of the underground karstic area of Slovenia, which in fact represents 50% of the state’s land, 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 lane with lanes for slow vehicles on higher slopes. ADT is up to 50,000.
### Table 1: Literature review on road runoff pollution on Europe

<table>
<thead>
<tr>
<th>ID</th>
<th>Complete Reference</th>
<th>Year</th>
<th>Country</th>
<th>Type</th>
<th>Monitoring study?</th>
<th>Brief resume of the study &amp; key pollutants</th>
<th>Modelling study?</th>
<th>Brief resume of the study &amp; modelling tool</th>
<th>Controllability of the studied impacted system or water body?</th>
<th>Available data?</th>
<th>Characteristics of the site</th>
<th>Resume</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Paper</td>
<td>SI</td>
<td>Slovenia</td>
<td>Conference Paper</td>
<td>No</td>
<td>No. Impacts on water bodies were estimated based on their spatial relations.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Paper deals with Slovenia as a whole. Slovenia is representing as a country rich in waters and where nearly water supply is coming from groundwater. Consequently there is many potential conflicts between drinking water protection zones and roads. Half of the country is covered by karstic aquifers, between 20 and 30 % is represented by intergestal aquifers which are unconfined and of high yield. Precipitation in the country is from more than 4000 mm/year on the mountainous region to 1500 mm/year on the Pannonian plain where continental climatic regime is already established. Roads are of different characteristics. In some parts highways have 70,000 ADT in other main highway lines it is not rising over 40,000 ADT. Slovenia has a number of drinking water resources, with their protected water exchange 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 cars going from Central Europe to the sea, on the border between Slovenia and Croatia, and so on. 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. During the planning, designing, construction, operation and maintenance of highways, groundwaters can be of important environmental and constructions constraint that can significantly influence the safety operation of traffic and big influence on the operational costs of highways. To classify and conceptualize the relation between groundwaters 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 presented 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.</td>
<td></td>
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</tr>
<tr>
<td>2007</td>
<td>Paper</td>
<td>SI</td>
<td>Slovenia</td>
<td>Paper</td>
<td>No</td>
<td>Study summarised results of previous investigations of run-off from karstic area.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>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.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2005</td>
<td>Paper</td>
<td>SI</td>
<td>Slovenia</td>
<td>Paper</td>
<td>No</td>
<td>Impacts on water bodies were estimated based on their spatial relations.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>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.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2013</td>
<td>Thesis</td>
<td>SI</td>
<td>Slovenia</td>
<td>Thesis</td>
<td>No</td>
<td>Study summarised results of previous investigations of run-off from karstic area.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>The site is positioned in NE Slovenia at the area where two large highway lines can form 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.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>2013</td>
<td>Conference Proceedings</td>
<td>SI</td>
<td>Slovenia</td>
<td>Conference Proceedings</td>
<td>No</td>
<td>Study summarised results of previous investigations of run-off from karstic area.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>The investigated site is positioned in the alkali 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 mm/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.</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
**WP1: PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF**

Task 1.1. Literature review on road runoff pollution on Europe

| ID | Complete Reference | Type | Year | Country | Monitoring study/ Brief summary of the study & key pollutants | Modelling study/ Brief resume of the study & modelling tool | Data availability | Conclusion
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>Brenčič M., Rikonavič R. (2000)</td>
<td>Paper</td>
<td>2002</td>
<td>SI</td>
<td>EN</td>
<td>No. Impacts on water bodies were estimated based on spatial relations. Yes. Modelling related to the spatial dimension of roads.</td>
<td>Yes</td>
<td>Paper is focusing on the runoff 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 2/3e with 1/3e with side lines on higher aisles. Precipitation amount is in around 1500 mm/year with intensive summer showers.</td>
</tr>
<tr>
<td>86</td>
<td>Brenčič M. (2004) Crossing of drinking water resources protection zones by roads (in Slovenian: Prečkanja osebnih vodovodnih zon in cest). Geologija, 45(2), 325-330</td>
<td>Paper</td>
<td>2004</td>
<td>SI</td>
<td>EN</td>
<td>No. Study analysed relations between drinking water protection zones and highway network. Yes. Modelling related to the spatial dimension of roads.</td>
<td>No</td>
<td>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 2/3e with 1/3e with side lines on higher aisles. Precipitation amount is in around 1500 mm/year with intensive summer showers.</td>
</tr>
<tr>
<td>83</td>
<td>Brenčič M., Suverkropp K., Ruby A., Tsay K. (2007)</td>
<td>Report</td>
<td>2007</td>
<td>FR</td>
<td>No monitoring results</td>
<td>Prepares 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</td>
<td>No</td>
<td>It presents a simple method to calculate road runoff loads (kg/hr) for SS, COD, Zn, Cu, Cd, Total Hydrocarbons and HAP. It splits annual road traffic volume in billions and above 10,000. Equations based on monitoring studies from Datar, since 1992. Also calculates average annual concentrations road runoff discharge. It uses a classification of &quot;open&quot; and &quot;restricted&quot; roads,differentiating the sections that are encroached (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, impervious surface annual rainfall depth (m) and a factorisation of reduction of works, within WP2.</td>
</tr>
</tbody>
</table>
| 88 | Kayhanian M., Suverkropp K., Ruby A., Tsay K. (2007) | Paper | 2007 | EN | Yes. 34 highways sites from California monitored during 2000-2003. Average 8 events/last/season of the year. pH, cond. hardness (SS, D, DOC, DOC total & dissolved metals (Al, Cu, Cd, Cr, Ni, Pb and Zn). Nutrients: N03, TNX, total P and ortho-P. | Yes | Yes | California is placed at a similar latitude as Southern Europe. Average annual rainfall range 152-1016 mm. Average annual precipitation range: 0.01-3.95 ha. Average annual runoff traffic range: 1800-32000. Surrounding land use types: Agriculture, rural, commercial, residential. Samples were analysed for conventional pollutants (pH, conductivity, hardness, and temperature); aggregates; TSS, TDS, "total" dissolved metals (Al, Cu, Cd, Cr, Ni, Pb, and Zn); and nutrients: N03-N, TNX, total P and ortho-P. | It presents a simplified method to calculate road runoff loads (kg/hr) for SS, COD, Zn, Cu, Cd, Total Hydrocarbons and HAP. It splits annual road traffic volume in billions and above 10,000. Equations based on monitoring studies from Datar, since 1992. Also calculates average annual concentrations road runoff discharge. It uses a classification of "open" and "restricted" roads, differentiating the sections that are encroached (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, impervious surface annual rainfall depth (m) and a factorisation of reduction of works, within WP2. | Very relevant Paper. Although not data from Europe it represents climate regions similar to Southern Europe and a complementable other sites in the USA. It also interesting to link with the PROPER tasks 1.2 and 1.4, since it presents a method to predict highway runoff constituents. | 53
Langeveld J., de Giesen N. K., Eriksson E., Kalmykova Ghassan C. (2012) Surfaces in a low intensity quality from roof and road stormwater: Part 1. Area, Charters F., Cochrane T., Markiewicz A., Björklund substance flow analysis, 54 WP1. Prediction of pollutant loads and concentrations in road runoff. Boogaard F., de Ven F., pollutants se organic pollutants from storm sewers in Paris. 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). Pollutant load and concentrations found in runoff were significantly different between the different surfaces. In addition, quantification and prediction of pollutant contributions from urban surfaces should consider the overall influence of different surfaces, instead of being aggregated into more generalized categories such as land use.


Maheljan B., Pashk N., Uijtendaal E. (2017) Stormwater monitoring. Monitoring results for 3 events at a 13.24 km² sub catchment of Talinn catchment area. 14.4% of the catchment area is road. Rainfall events were monitored and TSS and TP. Monitoring took place in 2015. No monitoring results.

Boogaard F., de Ven F., waters from mid December to late March. The 3 events monitored had different characteristics: 1) duration=2,3h and 6,2mm; 2) duration=26h and 6,2mm; 3) duration=2-3h and 5.1mm; 2) duration=26h and 6.2mm; 3) duration=13.5h and 9.7mm. No monitoring results.

Using three sampled storm events to estimate event mean concentrations and annual loads. The predictive capability of the model for quality is good and for quantity moderate. Although directly connected impenetrable areas, in particular roads and roofs, have relatively smaller areas they significantly impact runoff production up to 75% and loads up to 66% of the total suspended solids. The first flush at the beginning of the runoff is less important, but heavy rain and snowfall generate substantial runoff and pollutant 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.

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 loads over 150 locations throughout the Netherlands. The monitoring has been ongoing for nearly 15 years and 4,762 individual event samples were 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 literatures. The study found that the pollution loads at many of the Dutch test sites did not meet the requirements of the European WFD and Dutch Water Quality Standards.

The study provides results on stormwater pollution in Paris and its suburbs from three separate storm sewers in Paris. Pollutants such as Metals, PAHs, PCBs, organics, alkylphenols, phthalates, pesticides, and VCOs. Analyses conducted on both the particulate (P) and dissolved (D) phases.

This 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). Pollutant load and concentrations found in runoff were significantly different between the different surfaces. In addition, quantification and prediction of pollutant contributions from urban surfaces should consider the overall influence of different surfaces, instead of being aggregated into more generalized categories such as land use.

Although regarding an urban catchment it is interesting because data from Estonia (not so much available), providing detailed land use, rainfall and pollutants figures. It can be used for testing of modelling tools.

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 percentile) of between 60 to 1262 measurements for the several parameters, regarding Dutch residential areas. Also it includes a table comparing mean and median concentrations of stormwater pollutants in Dutch, Europe/Germany and worldwide.

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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 percentile) of between 60 to 1262 measurements for the several parameters, regarding Dutch residential areas. Also it includes a table comparing mean and median concentrations of stormwater pollutants in Dutch, Europe/Germany and worldwide.
The experimental site is located in “Sucy-en-Brie” municipality, a residential district within Paris conurbation. Threestream catchment consists in an 800 m2 portion (1/4 roadway width x 2 sides) of an urban road carrying moderate traffic loads (~3000 vehicles per day), with a runoff length of 160 m and an average slope of 0.8%. Runoff was collected by a stormman where the monitoring equipment was installed. 11-stripping buckets were used for flow-rate measurement corresponding to a 6.014 mm resolution in runoff height overtransparency area.

The usability of a commonly used accumulation and wash-off model for continuous modelling of urban runoff contamination was evaluated based on 11-years data from a highly trafficked road (AADT = 77 000 vehicles/day). Calibration and seasonal influences were incorporated into this model. Sensitivity and uncertainty analysis were performed using a Markov Chain Monte-Carlo sampling approach for both suspended solids and metals concentration modeling. Selected models failed at replicating suspended solids concentration event by 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 solids loads modelling, noticeably better performance was achieved, but similar results could as well be obtained with much simpler constant concentration models. Unlikely 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 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 concentration on fine particles, best management practices (BMPs) for 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 de-icing salt at cold weather conditions.

Confrontation of the “accumulation and wash-off” model with long-term continuous concentration data 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 concentrations 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 dissolved weight for other heavy metals as well. Seasonal changes were not significant for Cu, Zn, TOC and SS with manifold concentration increases during the melt season. A significant increase of Zn was observed between the mean concentrations in summer and winter season compared to mean concentrations in rain events. This can be traced back to less ground saturated 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 salt. 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 storm event to storm event. The mean values for the dissolved fractions were below 30% for Cu and Zn. Pb was completely undissolved.
Barbosa A. E., Fernandes J. N. (2012) Comparison of the pollutant potential of an integrated road runoff system with an area of 8.4 ha in Winterthur, Switzerland. This paper was Polyacrylic aromatic hydrocarbons and heavy metals.


Drainage, Global Solutions

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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### Table: Pollutant Loads and Concentrations in Road Runoff

<table>
<thead>
<tr>
<th>ID</th>
<th>Complete Reference</th>
<th>Type</th>
<th>Year</th>
<th>Country</th>
<th>Monitoring study?</th>
<th>Brief resume of the study &amp; key pollutants</th>
<th>Modelling study/ Brief resume of the study &amp; modelling tool.</th>
<th>Vulnerability of the receiving water body?</th>
<th>Available data?</th>
<th>Characteristics of the site</th>
<th>Resume</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>Stötz G. (1987)</td>
<td>Paper</td>
<td>1987</td>
<td>EN</td>
<td>Yes</td>
<td>Yes</td>
<td>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 (140,000 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) in the long-term yearly average (mm).</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>WP1: PREDICTION OF POLLUTANT LOADS AND CONCENTRATIONS IN ROAD RUNOFF</td>
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<td>102</td>
<td>Hallberg M., Renman G., Lundborg T. (2006)</td>
<td>Paper</td>
<td>2006</td>
<td>EN</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Runoff data was collected from a section of the European highway system E4 in the central area of Stockholm, Sweden. This Section consists of a six lane road made with asphalt surface. The total traffic load varied between 4300 and 144000 vehicles during time of sampling, while the average speed varied between 52 and 83 km/h. The AADT at this highway section is 120,000 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 relevant 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 run-off 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 experience 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 linear regression between the SS and the studied metals, verifying that in winter, the concentration of metals can be given by the concentration of SS.</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<td>303</td>
<td>Huber M., Holtmich B. (2016)</td>
<td>Paper</td>
<td>2016</td>
<td>EN</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>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 Co, 110 g/ha for Cr, 86 g/ha for Cd, and 1100 g/ha for Zn. 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.</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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