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Call 2016 Water Quality Final Programme Report - Environmentally Sustainable Roads: Surface- and Groundwater Quality

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Environmentally Sustainable Roads: Surface- and Groundwater Quality

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Cover photograph*: Soil retention filter planted with reed (Germany)*

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Executive Summary

The 2016 CEDR Transnational Road Research Programme call 'Environmentally Sustainable Roads: Surface- and Groundwater Quality' funded three complimentary projects (PROPER, LUNT and MICROPROOF) to review and critique research on the pollution impact of traffic and road-related activities on receiving water bodies, and to support its transfer into practice by the National Roads Authorities (NRAs). The aim of PROPER was to facilitate risk management in partnership with stakeholders. LUNT and MICROPROOF focussed on the environmental impacts of de-icing chemicals and organic micropollutants (OMPs) including microplastics; (MPs).

The project outputs can be categorised using the source-pathway-receptor concept as a framework. This approach enables the key findings, conclusions and recommendations to be presented and discussed thematically, helping users to both locate and access the full reports in relation to their core subject matter. The relationship between projects and deliverables is presented diagrammatically within a source-pathway-receptor flowchart (see Section 2.1). Each deliverable is referred to using the initial letter of its project title (as an identifier) followed by the report number. For example, P1.1 is the first deliverable of Work Package (WP) 1 in the PROPER project and L2.2 is the second deliverable of WP2 in the LUNT project.

In terms of sources, the potential significance of highway transport activities for receiving waterbody quality has been widely recognised. The three projects provide an overview of road- and traffic-related pollution, and factors that affect their quantities amounts and behaviours in the road environment. The prime pollution sources comprise traffic (fluids and solids/particulate associated with exhaust, body/engine corrosion, leakage and spillage, brakes and tyres); the highway surface (solids/particulate) and dry/wet deposition. Additional sources include de-icing chemicals during winter seasons, herbicides/pesticides if applied during maintenance works for weed and vegetation control, debris and litter, and corrosion of road signage and fixtures such as central barriers, railings, bridge decks etc. Temporary construction and road works activities can also generate additional solids and fluid emissions. These latter sources including accidental spillages represent 'event-source' pollution in contrast to the persistent 'routine-source' pollution driven by normal traffic and storm events. Emissions of pollutants in the traffic environment depend on factors such as traffic volumes (AADT) and composition (e.g. percentage of heavy good vehicles (HGVs)), driving patterns, (speed and brake use), road configuration, and highway surface type and age. Given the inherent variability and the stochastic nature of road runoff pollutant concentrations as well as their simultaneous release from multi-sources, it is difficult to quantitatively attribute individual source contributions to actual observed runoff concentrations.

With regard to pathways, there are a variety of mechanisms that may transport pollutants released in a highway environment to adjacent soil, surface waters and groundwater, including aerial routes, splash and spray (wet) with direct runoff, discharge after treatment and infiltration to groundwater either during or immediately after rainfall. Whilst the relative contributions of dry versus wet aerial depositions to highway runoff pollutant loadings is not well understood, factors identified to influence pollutant pathways include local weather conditions, road layout, traffic characteristics, topography, geo-physical conditions and type of road surface and design. The Dutch New National Model (NNM) has been applied to the downward transport of wear emissions (see P1.5) with the emphasis being on the larger particles (released by tyre, brake and road wear), that are expected to deposit near the road and not on the smaller exhaust emissions. Resuspension via air was found to represent the largest emission contribution to the total deposition followed by resuspension via splash and spray, which is limited to wet weather conditions.

In contrast to well-known highway pollutants (e.g. total suspended solids, metals and polyaromatic hydrocarbons), there is limited data on organic micropollutants (OMPs) and microplastics (MPs) in highway runoff. Therefore, the contributions that traffic might make to the concentrations of road and traffic related micropollutants/microplastic in surface waters and their pathways are still not fully clear. Although some literature exists on the concentrations of OMPs/MPs in surface water, the source of the reported pollutants and the contribution of road-traffic is often not traceable. For sustainable water protection, it is crucial to understand the behaviour of road runoff pollutants over the different transport pathways and in the treatment systems (Sustainable Drainage Systems, SuDS) to enable them to be constructed and operated based on the best management practices (BMP). The projects have shown that most pollutants are adsorbed and therefore efficiently retained by the most commonly implemented treatment measures including infiltration over the road shoulder. However, actual long term performance efficiency will be largely dependent on treatment design, layout and maintenance. Given pollutant removal in road runoff treatment systems, there is a need to know their ultimate fate over the longer term. Providing that the overall pollutant treatment behaviour is satisfactory, the NRAs are always interested in practical treatment solutions and encourage less-complex approaches which are able to fulfil the needs for water and environmental protection. The processes involved in retaining OMPs and MPs in highway runoff treatment systems are currently only understood at a generic theoretical level and this needs to be supported by experimental field studies directed at specific substances.

The impact of road runoff pollutants on receiving waters has been confirmed in some studies whereas others have shown no impact on freshwater ecology (Section 2.5). Although adverse effects on roadside vegetation and soils are commonly observed, the degree of impact varies between species. Fewer studies have considered the impact of highway runoff on groundwater quality but available data indicates that the downward transfer of pollutants e.g. metals in soils of SuDS/BMP is limited. The more soluble pollutants, such as chloride present in de-icing materials, can be nearly completely transferred to the shallow unsaturated zone.

The determination of the concentrations and loadings of pollutants in the highway environment is dependent on the collection of representative samples combined with the application of an accurate analytical methodology. Whilst reliable measurement techniques are available for the majority of pollutants (including metals and organic micropollutants) the assessment of microplastics is considerably less well established. The current status of the developments in this field is described and new data on a range of OMPs and MPs in highway environments is reported (see Section 2.4). Several models designed for the prediction of pollutant concentrations in highway runoff have been reviewed and applied to a range of existing data sets. It is concluded that models which have been calibrated and validated for a given site, region or country, are unable to accurately predict for different sites/regions without the necessary modification.

The protection of receiving waterbodies is considered in terms of a generic approach which considers pollutant properties and their behaviour under unit operating processes (UOP). This provides a pragmatic methodological approach to the identification and selection of appropriate SuDS/BMP options with an emphasis on treatment solutions which reduce annual loads discharging from SuDS/BMP controls rather than single event peak concentrations. In this respect, the “blue-green” UOP approach contributes primarily to mitigate long term chronic receiving waterbody impact rather than short term acute impact.

To support users in identifying when and where to treat highway runoff, the available decision support tools (DST) have been reviewed with recommendations made for their further development (e.g. SaltSMART). To address knowledge gaps, a series of new DSTs have been developed including:

- an approach for systematically assessing the relative vulnerability of receiving waters based on their inherent characteristics (Section 2.5.4)
- a flow chart to support users in identifying EU environmental legal constraints when planning, constructing and operating a highway (including guidelines on where to access necessary data layers so results may be visualised in a GIS format; Section 2.5.6)

- an MS Excel-based multi-criteria approach for identifying which of 12 individual SuDS/BMP treatment options are feasible for use at a particular site (based on site characteristic data) together with a benchmarked assessment of SuDS/BMP performance in relation to six criteria (supported by 12 indicators) (see Section 2.6.3.3)

Based on the findings of the PROPER, LUNT and MICROPROOF projects, this report concludes by identifying a series of measures that, if implemented by NRAs, would support a systematic shift towards the European road network being able to reduce its long term environmental impact on receiving waterbodies. The principal recommendations concern future continued implementation of source infiltration-based treatment systems, enhanced modelling capabilities and salting operations/technologies (Section 3.3). In addition to these recommendations for actions to be implemented now, a series of topics identified as areas where gaps in knowledge currently prevent or constrain NRAs from taking further steps in adopting sustainable highway drainage solutions are identified (Section 3.3).

GLOSSARY

AADT	Annual Average Daily Traffic
Al	Aluminium
BMP	Best Management Practice
BDL	Below Detection Limit
BOD	Biological Oxygen Demand
Br	Bromine
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CAS Number	Chemical Abstracts Service registry number
CDV	Czech Transport Research Centre Emission Model
CEDR	Conference of European Directors of Roads
Ca	Calcium
Cd	Cadmium
Cl^-	Chloride
COD	Chemical Oxygen Demand
COPERT	Computer Program to Calculate Emissions from Road Transport
Cr	Chromium
Cu	Copper
DMRB	Design Manual for Roads and Bridges
DO	Dissolved Oxygen
DRASTIC model	Index-Based Model to Estimate Groundwater Intrinsic Vulnerability
DSS	Decision Support System
EIA	Environmental Impact Assessment
EMC	Event Mean Concentration
ERA	Environmental Risk Assessment
EQS	Environment Quality Standard
Fe	Iron
GC-MS	Gas Chromatograph – Mass Spectrometry
GI	Green Infrastructure
GIS	Geographic Information System
HAWRAT	Highways Agency Water Risk Assessment Tool
HBEFA	Road Traffic Emission Factor Model
HGV	Heavy Goods Vehicle
K_d	Partition Coefficient
LID	Low Impact Development
LUNT	The second project of this research call “Environmental Impacts of De-icing Chemicals (EvIDenCe)”
MEFA	Czech Road Traffic Emission Factor Model
mg/vkm	Milligram/Vehicle Kilometre
MICROPROOF	The third project of this research call “Micropollutants in Road Runoff”
Mn	Manganese
MPs	Microplastics
NaCl	Sodium chloride
NPDES	National Pollution Discharge Elimination System
NEE	Non-Exhaust Emissions
NH_3	Ammonia
Ni	Nickel
NNM	New National Model (Netherlands)
NRA	National Roads Authority

NO_x	Nitrogen oxides
OMPs	Organic Micropollutants
UOP	Unit operating process
PAH	Polyaromatic Hydrocarbons
Pb	Lead
PCB	Polychlorinated Biphenyl
PEC	Predicted Environmental Concentration
PNEC	Predicted No-Effect Concentration
PROPER	The first project of this research call "Road Runoff Pollution Management and Mitigation of Environmental Risks"
Pd	Palladium
Pt	Platinum
Rh	Rhodium
RICH	Rating and Identification of Chemical Hazards
RSS	Risk Assessment of Road Stormwater Runoff
S	Sulphur
Sb	Antimony
SELDM	Stochastic Empirical Loading & Pollution Model
Si	Silicon
SMC	Site Mean Concentration
SoAR	The State-of-the-Art report prepared by the CEDR Task Group 15 (Water Quality)
SuDS	Sustainable Drainage Systems
SYMOS	Czech Stationary Sources Modelling System
TiO_2	Titanium dioxide
TMDL	Total Maximum Daily Load
TRWP	Tyre and Road Wear Particles
TSS	Total Suspended Solids
ug/vkm	Microgram/Vehicle Kilometre
VOCs	Volatile Organic Compounds
WFD	Water Framework Directive
Zn	Zinc
ZnO	Zinc oxide

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1 Introduction

Because of the demands within modern society for efficient transport and mobility, roads have become pervasive in the landscape and may cause harm to public health as well as the environment because of their short- and long-term physical, chemical and biological impacts. Increased traffic loadings and building of new roads can lead to serious threats to the aquatic environment due to the discharge of contaminated runoff. Therefore an awareness of the environmental constraints of roads is important and pollution reduction is a key challenge for NRAs.

A key output of the CEDR Task Group 15 (Water Quality) was the development of a state-of-the-art report (SoAR) on current practices and research needs associated with the management of highway runoff in several European countries (Meland, 2016). Most road projects across Europe are subject to environmental impact assessment, where the likely significant effects of the project on the environment must be considered. The SoAR recognised the current consensus that road runoff may impair receiving waters and concluded that all countries should address environmental aspects when constructing and operating roads as part of multi-sector partnerships to, for example, meet the regulatory requirements of the EU Water Framework Directive (EU WFD, 2000). Moreover, in many cases in some European countries, road projects will be subject to requirements based on Articles 6 (the Habitats Directive) and 12 (species protection or Birds Directive) (Natura, 2000). These aspects are not a major part of the current project.

The 2016 SoAR noted the increasing use of sustainable drainage systems (SuDS/BMPs) as an example of best available technology for highway runoff treatment, but also a range of knowledge and implementation gaps related to when and how road runoff should be treated. Based on its review of the literature and NRA practice, the report identified a list of research needs. This list directly informed the development of the 2016 CEDR Transnational Road Research Programme call ‘Environmentally Sustainable Roads: Surface and Groundwater Quality’.

2 Synthesis of PROPER, LUNT and MICROPROOF key findings

The primary aim of the 2016 research call was to review, critique and facilitate the implementation of research into practice by NRAs. Further, whilst the 2016 SoAR focused on the impact of the construction and operation of roads on receiving water chemistry, it also noted that the impact of road-related activities on the physical (habitat) and ecological quality of receiving waters was important. This led to the recommendation that the NRAs should work more closely with environmental agencies to develop proportionate responses to the risks posed to receiving water by highway runoff. To support implementation of this recommendation, the SoAR suggested 'five ways forward'.

2.1. Support navigating between projects and deliverables

The current report synthesizes the findings of the three consortia funded under the 2016 CEDR Transnational Road Research Programme call "Water Quality" with a view to supporting the user-oriented requirements of the Project Executive Board (PEB). It also reviews the new research findings which have been identified by Meland (2016) and the NRA-environmental agency implementation activities. An overview of the scope and key activities of each of the three funded projects (PROPER, LUNT and MICROPROOF) is provided in Figure 2.1.

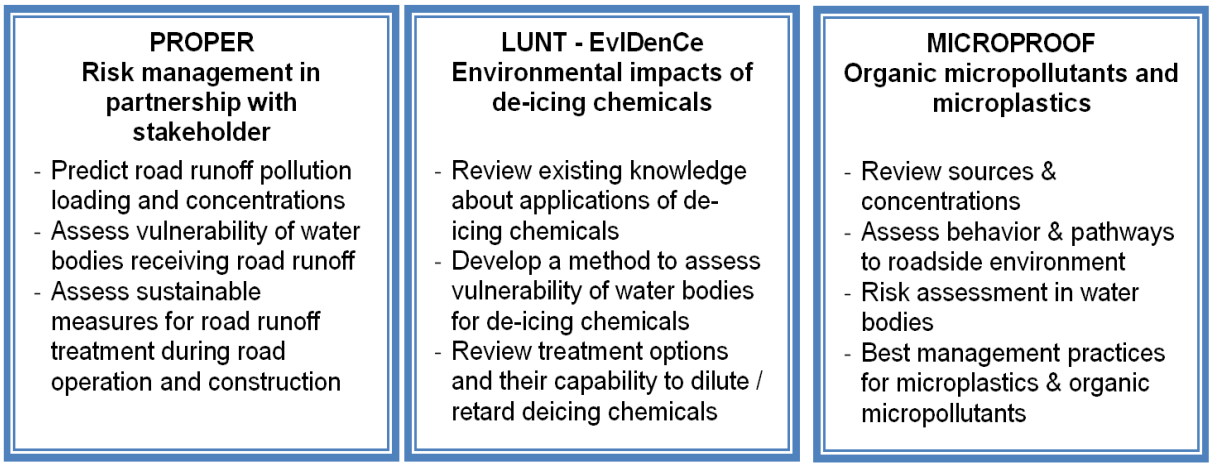

Figure 2.1. Scope and key activities of the three projects

The three projects have developed a total of 36 deliverables. A list of all project deliverables is given in Appendix 1. All deliverables are accessible at their respective project websites in addition to the CEDR website (www.cedr.eu).

To facilitate users in navigating between the deliverables, they have been arranged within a source-pathway-receptor (SPR) format according to their content (see the flowchart in Figure 2.2). Each deliverable has a project identifier (letter; followed by the report number as follows:

- PROPER deliverables commence with P e.g. P1.1
- LUNT deliverables commence with the letter L e.g. L1.1
- MICROPROOF deliverables commence with the letter M e.g. M1.1

Where a deliverable covers more than one topic e.g. sources and pathways, this deliverable is then identified in association with both topics. For example, P2.1 (A review of current knowledge on the vulnerability of European surface water and groundwater to road related pollution) is identified in Figure 2.2 as containing information related to both pathways and receptors. The SPR structure assists the synthesis of the results from all three projects allowing due consideration of mechanisms to support the uptake of research into NRA practice. Sources and pathways are considered in Sections 2.2 and 2.3, respectively whereas Section 2.4 describes data measurement and data prediction. Receptors and impacts are presented in Section 2.5 with treatment and management in Section 2.6. The report considers how the issues raised in the

SoAR and DoRN (2016) have been addressed in Section 3.1 It also includes an overview of the final combined workshop (Section 3.2) and identifies measures to support implementation in Section 3.3. Also in Section 3.3, the major outcomes and recommendations for further research needs are presented together with an indication of how addressing these would enhance the sustainability of an environment-friendly European road transport network.

2.2. Sources and pathways of road and traffic related pollution

The potential significance of highway transport activities for receiving waterbody quality has been widely recognised (Muller et al., 2020). The prime pollution sources are derived from traffic (fluids and solids/particulates associated with exhaust, body/engine corrosion, leakage and spillage, brakes and tyres), the highway surface (solids/particulate) and dry/wet deposition. Additional sources include de-icing chemicals during the winter season, herbicides/pesticides if applied during maintenance works for weed and vegetation control as well as debris, litter, road signage and fixture corrosion derived from central barriers, railings, bridge decks etc.

Temporary construction and road works activities can also generate additional solids and fluid emissions. These latter sources including accidental spillages represent '*event-source*' pollution in contrast to the persistent '*routine-source*' pollution driven by normal traffic and storm events which, whilst variable in character, occurs on a recurrent daily basis.

Deliverable P1.1 has analysed more than 100 references related to road and traffic pollution, pollutant sources, monitoring and patterns. In summary, pollutants in road runoff can be classified according to different aspects such as exhaust and non-exhaust pollutants, conventional water quality parameters (e.g. TSS), metals, nutrients (e.g. nitrates and phosphates) and organic substances (e.g. PAHs). Table 2.1, which is essentially based on information extracted from French and Swiss highway studies (quoted by Piguet (2007)), identifies various substances associated with differing sources in highway runoff (M1.1).

The levels of pollutants emitted in the highway environment depend on factors such as traffic volumes (AADT) and composition (percentage HGVs), driving patterns, (speed and brake use), highway surface type and age, and climate conditions. Solids deposited on road sections characterised by high braking, acceleration and decelerating activities generally contain higher metal concentrations compared to other locations along the road (Huber and Helmreich, 2016). Given the inherent variability and stochastic nature of road runoff pollutant concentrations as well as their simultaneous release from multi-sources, it is difficult to quantitatively attribute individual source contributions to actual observed runoff concentrations. The following sections give an overview on how the three projects (PROPER, LUNT and MICROPROOF) have summarized the sources of road and traffic related pollutants.

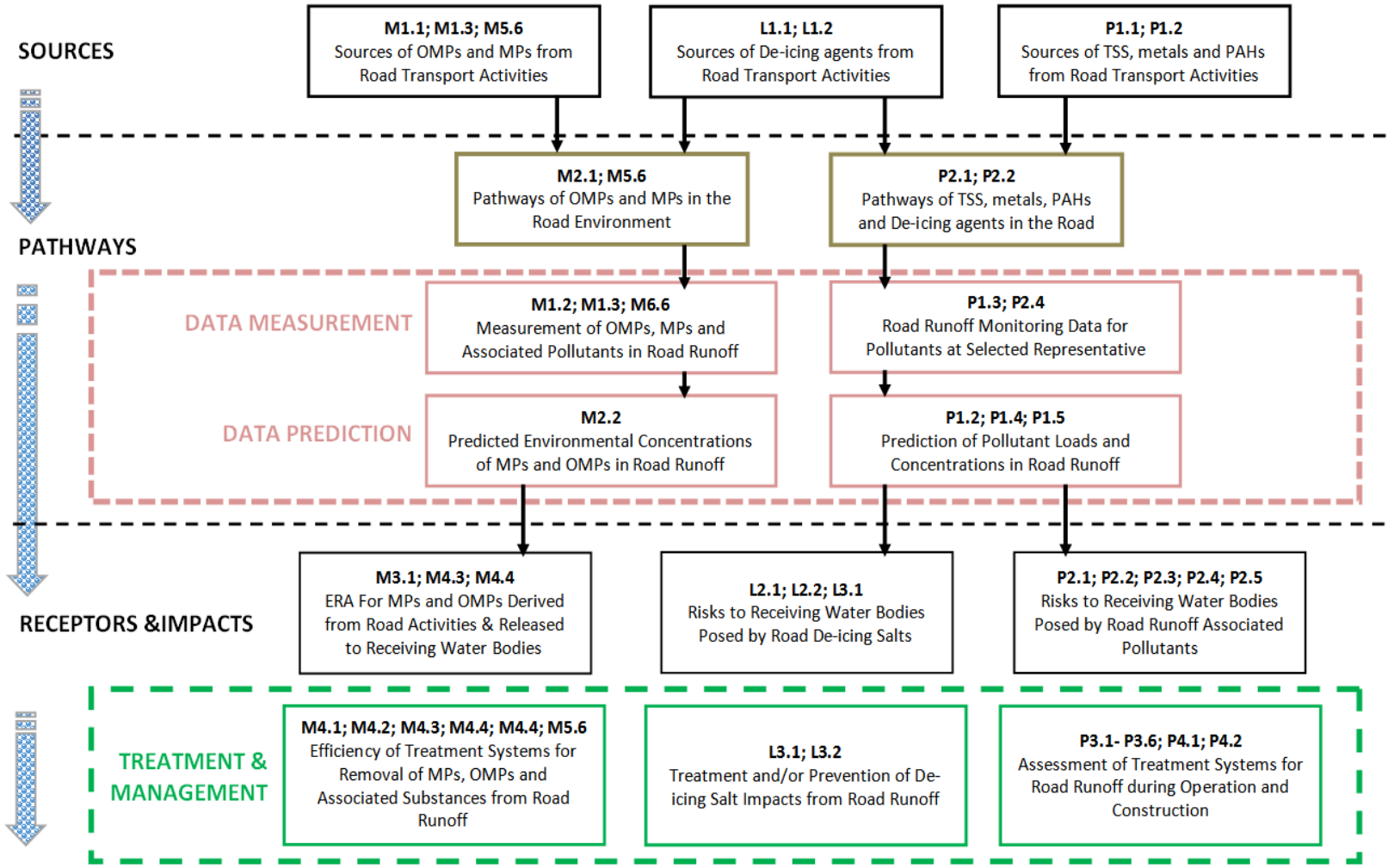

Figure 2.2. Sources, pathways, receptors flowchart identifying content and linkages between PROPER, LUNT and MICROPROOF deliverables

Table 2.1. Sources of pollution (including associated substances) in highway runoff (Piguet, 2007)

Routine-Source	Substance
Carburant, gasoline/diesel	Pb, Ni, Zn, OMPs, PAH, BTEX,
Oils, lubricants, grease	Pb, Zn, Ni, PAH, BTEX, PCB
Exhaust gas	Br, Pb, Ni, PAH, BTEX, MTBE, NOx, OMPs
Exhaust catalyser	Pt, Pd, Rh, PAH, BTEX, MTBE
Brakes	Cu, Cr, Ni, Mn, Pb, Cd, Sb, Zn, solids / particulate, OMPs
Tyre wear	Rubber/solids, particulate, OMPs, MPs, S, ZnO, Cd, Pb, Cu
Highway surface wearing course	Solids/particulate, colloids, Zn, Si, Ca, Mn, PAH, MPs
Concrete	TSS
Asphalt	TSS, PAH, OMPs
Tar/Bitumen	OMPs, PAH
Signage/marking paints	TiO_2, MPs
Railings, signals etc.	Fe, Zn, Cr, Ni
Engine/body corrosion	Al, Cu, Fe, Co, Mn, Pb, Cr, Ni
Events: construction, works and maintenance activities; spillages, road salting	Na, Cl, Cl^-, Ca, SO_4^{2-}, herbicides/pesticides, MPs, OMPs, litter, debris

2.2.1. Sources of TSS, metals and PAHs from road transport activities

The common pollutants reported in the European source studies are TSS, heavy metals and organic pollutants such as PAHs. Several studies have reported considerable as well as variable concentrations of metals such as iron, copper, lead, and zinc in the brake linings with copper being the most abundant metal in almost all brake linings. Other metals such as barium were found in the wear of brake linings in a large range of concentrations. Several cited studies have revealed different concentrations of cadmium, chromium, nickel, lead, antimony, potassium, titanium, and tin in the emissions of brake linings.

According to the literature, the wear of tyres is composed mainly of 42% rubber, 34% particulates, 17% mineral oils, and 7% other materials including PAHs, lead, and calcium oxides. Though several trace metals are incorporated in tyre production, zinc has been found in significant amounts in tyre wear samples, as it enhances the ability of tyres to absorb frictional heat.

Traffic-derived PAH emissions appear to have diminished by an order of magnitude over the past 15–20 years. Much of this reduction is possibly attributable to a methodological effect which has led to changes in manufacturing guidelines. The introduction of EU Directive 2005/69/EC, which limits the presence of extender oils in tyres, is also believed to be a factor. Several researchers over the last few decades have attempted to report the concentrations of pollutants in road surface material including specific organic compounds. The current projects have reported that different PAHs and several metals such as arsenic, vanadium, nickel, iron, magnesium, calcium, chromium, copper, and zinc have been detected at different concentrations in several analytical studies of bituminous materials.

Figure 2.3 illustrates observed increases in winter pollutant runoff levels (TSS, metals, PAH) recorded for runoff from the A34 trunk road at Newbury in southern England to the Gallos Brook (Crabtree et al., 2008). Winter spikes in Zn and Cu can be observed. Very similar patterns in TSS,

metals and PAH trends following winter road salting operations have been reported in most monitoring studies being correlated with highway salting applications. This confirms the conclusions noted in the LUNT literature studies (L1.1) on road salt application. However, given the potential interfering and interacting variables of site, traffic and event characteristics, any cause-effect relationship between source and runoff concentrations will inevitably be variable, site-specific and inconclusive in terms of universal generic application.

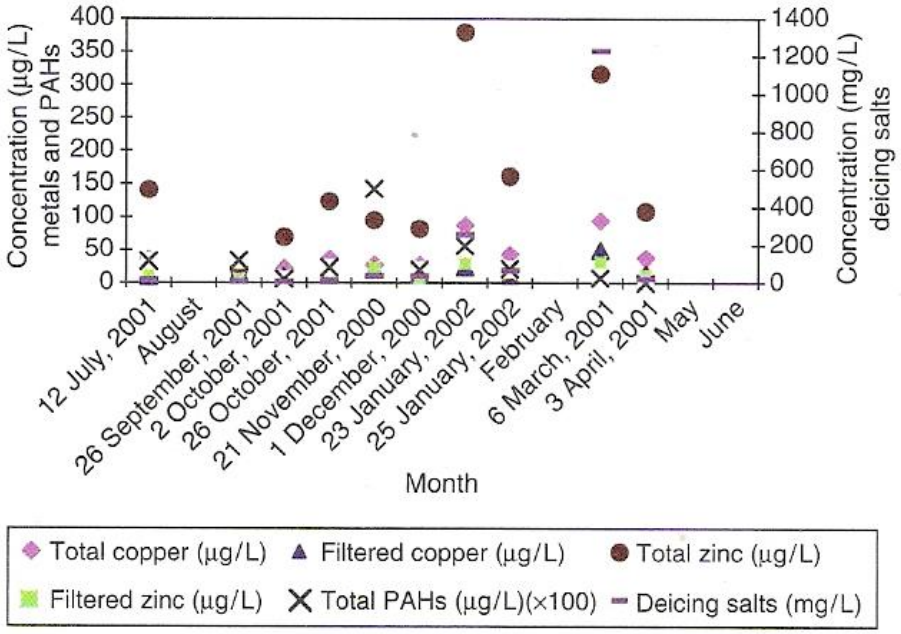

Figure 2.3. Seasonal pattern in road runoff data from A34 Gallos Brook in the UK (adapted from Crabtree *et al.* 2008)

The MICROPROOF Deliverable (M1.1) concludes that despite an apparent large literature base, good quality, 'hard' verifiable data regarding the range, concentrations and sources of highway runoff pollution is lacking with only a few references being classified as 'highly relevant' and relating to French (Legret, 2001; Piguet, 2007), UK (Crabtree et al., 2006), German (Huber and Helmreich, 2016) and US studies (Kayhanian et al., 2007 and 2012). The review did not consider the comprehensive database available from Irish highway runoff studies (Higgins, 2007; Bruen et al., 2006). The M1.1 review suggests that the median concentration of most pollutants were some 20%-30% higher in European runoff than found in North American studies, although reasons for this discrepancy were not investigated. PAH concentrations recorded in southern Europe (Portugal, Spain) also appeared to be frequently below detection limits with maximum levels rarely exceeding 0.08 µg L^{-1} (Barbosa et al., 2011).

One unresolved issue is that of discriminating between source exhaust and non-exhaust pollutant emissions (NEE) and in quantitatively assessing their relative contributions to total site runoff concentrations. The magnitudes of non-exhaust emissions are, however, highly uncertain, particularly when compared to data for exhaust emissions. Emissions vary widely according to brake, tyre and road-surface material, and with driving style.

The NEE emission factors used in inventories have a wide span of uncertainty – greater than a factor of two is typical – including uncertainty in terms of particle size fractionation. The emission factors are also largely based on data from the 1990s and have not changed as vehicle designs and fleet compositions have changed, in contrast to the regularly updated factors used for exhaust emissions. The available data indicate that brake, tyre and road-surface wear contribute approximately equally to sources of NEE, and are predominantly derived from cars because of

the much greater vehicle-km travelled for this class of vehicle. Emissions may be high at locations such as motorway/trunk-road exits.

'Routine-source' highway operations have been diagnostically benchmarked in the PROPER deliverable P2.2 as a basis to derive indicators of risk and vulnerability. The principal influencing factors of source runoff quality are cited as traffic, site and climate conditions. These source indicators can be benchmarked e.g. traffic AADT, site area, rainfall intensity etc., and scored or weighted to reflect their significance in terms of their potential operational risks. The extrapolation of current source predictive modelling approaches is considered at best to be a first-order screening evaluation and not offering a viable generic basis for universal application.

A further concern is also expressed about the uncertainty regarding the soluble and insoluble fractions of organic micropollutants discharged by highway runoff and the implication for longer term chronic effects of persistent episodic ultra-low emissions to receiving water bodies which deserve to receive more detailed attention. The review recommends that a harmonised pan-European approach is taken to develop and test a common database matrix for site source data monitoring which can facilitate a more robust comparison of site data and provide a basis for more accurate and reliable generic modelling (P2.2). However, the review concludes that source-runoff modelling is still likely to remain a challenging issue for highway authorities.

2.2.2. Sources of organic micropollutants (OMPs) and microplastics (MPs) from road transport activities

There is a shortage of reliable, good-quality source data and information on microplastics and organic micropollutants (other than PAHs) for highway runoff. This includes a number of important organic micropollutants associated with the road environment including benzothiazoles, benzotriazoles, amines, phthalates, alkylphenols, bisphenol A, melamines, polyglycol ethers etc..(see Table 2.4). Thus whilst there is a skeleton base literature on these micropollutants for receiving surface waters, it is not clear what their specific sources might be. It is difficult, if not impossible at the present time, to reliably attribute the share of these receptor waterbody micropollutants specifically to traffic-derived sources or even why they should be found in highway runoff.

Traffic emission factors (M1.1) are separately tabled for microplastics (Table 2.2; expressed as mg/vkm) and organic micropollutants (Table 2.3; expressed as µg/vkm). Exhaust emissions have been excluded on the basis of their being essentially airborne rather than being direct deposition emissions to the highway. However, this assumption is not necessarily true for exhaust emitted particulates which have the potential to be washed-out during any rainfall event and thus contribute towards highway runoff pollution.

An important source of MPs and OMPs is concluded to be from tyre wear/abrasion with average emission factors from this source being 39-1500 mg/vkm (M1.1) (e.g. Klein et al., 2018). Emission factors from road markings and asphalt are considerably less, in the range of 0.2-15.3 mg/vkm (Magnussen et al., 2017; Lassen et al., 2015). By far the highest emission proportion per kilometre is associated with heavy goods vehicle (HGVs). Tyre particulate and microplastics appear to primarily accumulate close to the roadside margins from where they may be re-distributed by overland flow and infiltration. The reported emission factors cover a range of three orders of magnitude with the highest being for N-(1,3-dimethylbutyl)-N'-phenyl-1,4-phenylenediamine (150 µg/vkm) and 1,3-diphenylguanidine (46.5 µg/vkm) both from tyres and the lowest being PAH 16 (0.09 µg/vkm) from brakes.

Unfortunately, the majority of the identified organic micropollutants have either not or only sporadically been measured in stormwater runoff, road dust and soil. Table 2.3 identifies the OMPs that could be relevant for water quality and which are recommended to be measured more

frequently in road run-off and/or associated with the pathways to surface water bodies (M1.1). Organic micropollutant frequencies of occurrence followed the priority order based on relative toxicity: shown below.

Polycyclic aromatic hydrocarbons (PAHs) > alkanes C20 - C40 > alkylphenols > phthalates > aldehydes > phenolic antioxidants > bisphenol A > oxygenated-PAHs > naphtha C5 - C12 > amides > amines

However, only PAHs are consistently reported and in sufficient detail to enable a listing of potential sources which are mainly associated with lubricants and tyres (M1.3. Annex A; Table 5). Measured concentrations of PAHs are also reported in M1.3 (Annex B: Table 7).

Table 2.2. Emission factors for microplastics (mg/vkm; total amount released from traffic and roads which end up on the road surface, in soil and surface waters)

Sources	**Emission factor (**mg/vkm)	**References**
Tyre wear, passenger cars	50 - 132	Gustafsson, 2001; Hillenbrand et al., 2005; GRPE, 2013; Azarov et al., 2014; Klein et al., 2018
Tyre wear, light commercial vehicles	102 - 320	GRPE, 2013; Azarov et al., 2014; Klein et al., 2018
Tyre wear, trucks/commercial vehicles	546 - 1500	Hillenbrand et al., 2005; GRPE, 2013; Azarov et al., 2014; Klein et al., 2018
Tyre wear, buses	267 - 700	Gustafsson, 2001; Hillenbrand et al., 2005; GRPE, 2013; Klein et al., 2018
Tyre wear, motorcycles	39 - 47	Hillenbrand et al., 2005; Klein et al., 2018
Tyre wear, average	90 - 270	Pant & Harrison 2013; Sundt et al., 2014; Lassen et al., 2015
Asphalt	0.19	Microplastic emission of 1500 ton divided by total vehicle kilometers (data from Magnussen et al., 2017)
Road marking	2.43 - 15.27	Microplastic emission of 100-690 ton divided by total vehicle kilometres (data from Lassen et al., 2015)
Brakes	-	No data available
Vehicle parts	-	No data available

A listing of priority (WFD-designated) organic micropollutants (OMPs) found in highway runoff and derived from tyre, brakes, brake fluid, vehicle coatings and coolant sources is given in Table 2.4. More studies on the pathways and ecotoxicological relevance of substances in receiving water bodies are needed. Since most OMPs tend to be adsorbed they will be retained by the most commonly implemented treatment measures. In spite of this potentially efficient removal there is still a need to understand the long term behaviour of OMPs as they build-up in the sediments of road runoff treatment systems. This is consistent with the NRA's goal of supporting practical solutions and less complex approaches as long as they fulfil the needs for water and environmental protection.

Although a limited literature exists on the concentrations of microplastics (MPs) and organic micropollutants (OMPs) in surface water, the source of the reported pollutants is not always traceable. For some sources, there is no information on the exact composition of a material and therefore on the exact composition of the emissions.

Because the number of actual measurements is limited, the authors of the MICROPROOF project strongly recommended that more measurements are conducted for both OMPs and MPs in road runoff. In addition, more data needs to be collected on the pathways and impacts of these pollutants. Given the data paucity and uncertainty it is not possible to disregard the potential

adverse long term impacts particularly from persistent episodic, low-level source pollutant concentrations. In addition, the generic risk assessment and associated source data base is insufficient to be reliably or robustly applied to a specific highway site location which would require local conditions and circumstances to be considered. A major recommendation of M1.1 is for further detailed monitoring and experimental studies to determine the specific source concentrations and loadings of these micropollutant groups in highway runoff.

Table 2.3. Emission factors for organic micropollutants (µg/vkm; total amount released from traffic and roads which ends up on the road surface, in the soil and in surface waters)

Sources	Chemical	Short name	CAS number	Emission factor (mg/vkm)	Ref
Tyres	1,3-Diphenylguanidine	DPG	102-06-7	46.50	1)
	2-Benzothiazolone	BTON	934-34-9	3.00	1)
	2-Mercapto benzothiazole	MBT	149-30-4	1.13	1)
	4-Aminodiphenylamine	4-ADPA	101-54-2	2.55	1)
	4-Hydroxydiphenylamine	4-HDPA	122-37-2	6.30	1)
	Aniline		62-53-3	0.30	1)
	Benzothiazole	BT	95-16-9	5.25	1)
	Cyclohexyl amine	CHA	108-91-8	4.95	1)
	Diphenylamine	DPA	122-39-4	0.32	1)
	N-(1,3-dimethylbutyl)-N'-phenyl-1,4-phenylenediamine	6-PPD	793-24-8	150.00	1)
	N-cyclohexyl-1,3-benzothiazol-2-amine	NCBA	28291-75-0	0.30	1)
	PAH-8			4.20	2)
Brakes	Polyalkylene glycol ethers			4.85	3)
	N-alkanoic acids			2.92	3)
	PAH-16			0.09	3)
Lubricants	PAH-16			7.25	4)

Key of references: (1) Unice et al., 2015 (concentration in fresh TRWP) combined with an average rubber emission factor of 150 mg/vkm (average of Pant and Harrison, 2013; Lassen et al., 2015; Sundt et al., 2014); (2) Pan et al, 2016 (tyres with Bay-H%<= 0.35%), combined with an average rubber emission factor of 150 mg/vkm (average of Pant and Harrison, 2013; Lassen et al., 2015; Sundt et al., 2014); (3) Emission factor of brakes (Grigoratos et al., 2015) multiplied with content (Rogge et al., 1993); (4) Lubricant leakage of 10 mg/vkm (Klein et al., 2018) multiplied with PAH content (Deltares and TNO, 2016)

Table 2.4. Organic micropollutants identified as relevant in the highway environment based on their identification as a priority substance within the Water Framework Directive (WFD) and on whether emission factors and/or concentrations in runoff have been measured

Source	Substance	Emission factor (µg/vkm)	Runoff concentration (µg L^{-1}) with reference in brackets
Tyres	Benzothiazole	5.25	5.68-11.80 (1); 1-5 (2); 0.4-1.4 (3)
	Mercaptobenzothiazole	1.13	0.11 (4)
	Benzothiazolone	3.00	
	Hydroxybenzothiazole		0.17 (4); 5-22 (2); 0.8-7 (3); 0.81 (5)
	Benzothiazole-2-sulfonate		12-44 (2)
	2-(methylthio)-benzothiazole		0.11 (4)
	2-Morpholinobenzothiazole		0.2-0.2 (3)
	Cyclohexylamine	4.95	
	Dicyclohexylamine		
	Hydroxydiphenylamine	6.30	
	Aminodiphenylamine		
	Aniline	0.30	
	*PAH	4.20	2.49 (6); 0.06-0.55 (7); <0.01-5.3 (8); 0.1-0.75 (7); 0.6 (9); 2.8 (5); 0-2.84 (10); 0.01-62.19 (11); 0.17-1.06 (7)
Brakes and brake fluid	Polyglycol ethers	4.85	
	Boric-acid-ester		
	Tributylphosphate		
	Triethanolamine		
	*PAH	0.09	See above
Car coatings	Hexa(methoxymethyl)melamine		0.66 (4); 0.01-0.88 (12)
	Nonylphenol ethoxylates		0.16 (13)
	Octylphenolethoxylates		0.01 (13)
	Bisphenol A		0.55 (13)
Coolants	Benzotriazole		
	Tolyltriazole		2.30 (4)
	Mercapto benzothiazole		0.11 (4)
	Diisodecyl phthalate		8.60 (5)
	*Di(2-ethylhexyl)phthalate		2.27 (5)
Other	Tris(1-chloropropan-2-yl) phosphate		0.13 (5)
	Nonylphenol monocarboxylate		0.47 (13)
	*Nonylphenol		0.36 (13)
	*4-tert-octylphenol		0.06 (13)

Key of references: (1) Baumann & Ismeier, 1998; (2) Kloepfer et al., 2005; (3) Reddy & Quinn, 1997: (4) Seitz & Winzenbacher, 2017; (5) Holstein, 2014; (6) Brongers, 2010;; (7) Van Velsen, 1997; (8) de Best et al., 2003; (9) Berg, 2009; (10) Schipper, 2003; (11) Meland, 2016; (12) Dsikowitsky & Schwarzbauer, 2015; (13) Gasperi et al., 2014; * Indicates that the substance is a listed Priority Substance in WFD.

2.2.3. Sources of de-icing agents from road maintenance activities

De-icing salts have been used in road maintenance in order to sustain road safety and accessibility in winter periods through enhancing the grip between tyres and the road surface. The LUNT project has considered chloride-based de-icing agents including sodium chloride, magnesium chloride and potassium chloride. Sodium chloride (NaCl) is the most commonly used de-icing agent due to low price, ready availability, ease of storage and handling, and relatively low environmental impacts. Consequently, hundreds of thousands to millions of tons of road salts are being applied annually in different parts of the world, often without appropriate documentation of application rates, distribution, or frequency. For example, de-icing salts were applied in Germany for the first time in 1930 and the amounts of de-icing salt used increased dramatically from the 1960s to about 2 million t/a in the year 1970 followed by a decrease by 1975. The amounts of de-icing salts applied in Germany have fluctuated recently with a maximum application rate of 50t/km being observed in the winter of 1969/1970 (Aljazzar and Kocher 2016).

Application technologies suggest that salt solution sprayings can have longer lasting effects, especially when applied to dry or lightly wet road surfaces, in comparison to application as a salt-slurry or as moistened or dry salt. Salting reductions of up to 40% can be achieved by such solution application. Major organisational objectives are stated as being the achievement of optimal application rates and improved procurement processes and application technologies. Most national highway maintenance manuals tend to stipulate regulation in terms of a road standard rather than an application rate (Rosewth and Jakob, 2010).

Nordic and North American literature (Amundsen et al., 2010; NCHRP, 2007; Marsalek, 2003) indicates that greater than 80% of applied surface water and highway drainage chloride loads pass directly to the receiving waterbody. Such contaminated runoff results in frequent exceedances of environmental quality standards (EQS) or acute water quality criteria (Rivett et al., 2016; Corsi et al., 2015), often also being associated with a decrease in in-stream species and diversity (Stranko et al., 2013; Marsalek, 2003). Many European and US lakes are also reported as developing adverse permanent chemolines or chemical layering (Dugan et al., 2017). The LUNT NRA questionnaire review (L1.2) considers that further knowledge advances need to be made particularly in the fields of source sensor technology and knowledge transfer. The review suggests that such transfer might be reinforced by regular (annual or biennial) NRA cross-collaboration on a pan-European questionnaire on salting application. A growing operational source concern is a perception of an increasing divergence and inconsistency between the NRA core mission of road safety and local environmental impacts related to road salting applications.

Groundwater impacts due to de-iicing salts are less well understood than for surface waters with largely outdated prediction equations for unsaturated zone flow analysis being reliant on uncertain K_d values related to soil type and the existence of highly variable ion exchange capacities. Salt dispersion in the main direction of groundwater flow can be 10 to 20 times that occurring in secondary dispersion directions (Kitterod, 2008). Induced dispersion of soil organic matter resulting from road salting is considered to be the dominant mechanism of metal mobilisation in the unsaturated zone (Werkenthin et al., 2014). There is therefore much less knowledge and awareness of the possible impacts and issues associated with soils adjacent to highways and with roadside infiltration-type SuDS/BMP systems. This includes the potential remobilisation and transport of metals and other micropollutants such as hydrocarbons from soil wash-out during runoff events. It is considered that the impact of chloride-based roads salts on soil structures and mobilisation processes underlying highway infiltration-type treatment systems remains at best speculative and justifies more attention in order to support appropriate treatment and management approaches.

2.3. Pathways of road and traffic related pollutants

Exhaust-emission gases released into the ambient atmosphere can undergo chemical reactions that produce secondary particulates. Primary particulates are those that are directly emitted from the tailpipe or from non-exhaust traffic related sources. Larger particulates (greater than 10 µm) tend to settle to the ground whereas smaller particulates stay longer in the air. Rainwater also has the potential to facilitate the deposition of primary and secondary airborne particulates. Particles that deposit on road surfaces are mixed together with particles released from other ground sources and form the road bulk-pollutants. Road runoff transports traffic pollutants (particulates, particulate-sorbed pollutants and dissolved pollutants) from the road surface to the surrounding environment.

The different pathways by which pollutants are released in the highway environment including transport to adjacent surface waters and groundwater are shown in Figure 2.4. Aerial routes include direct airborne dispersion, resuspension or wind dispersion (dry), splash and spray (wet) with direct runoff, discharge after treatment, and infiltration to groundwater occurring either during or immediately after rainfall (see MICROPROOF Deliverable 2.1 (M2.1)). Runoff concentrations are often related to rainfall intensities with several studies also reporting a first flush effect. Several reported monitoring studies refer to site-specific correlations between source pollutant concentrations and site/weather conditions.

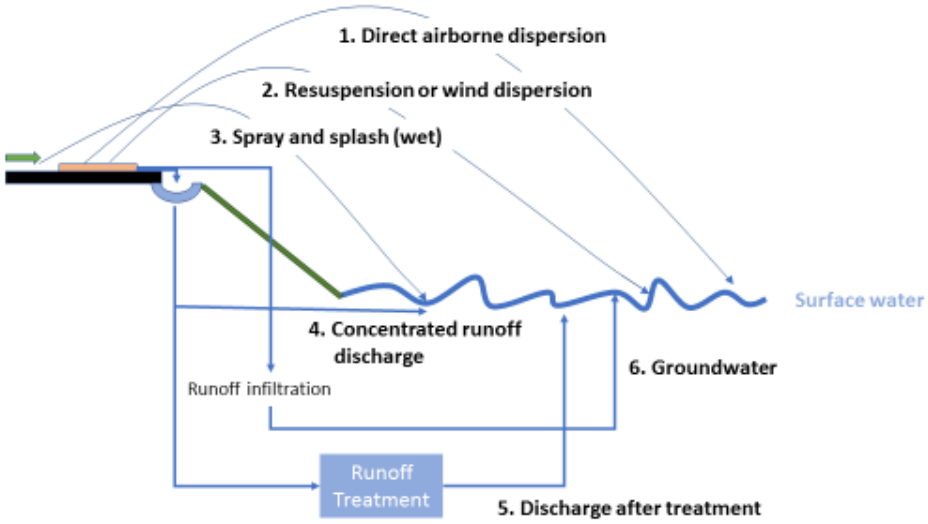

Figure 2.4: Pathways by which road associated pollutants can be transferred to surface water and groundwater (MICROPROOF Deliverable 2.1 (M2.1))

The LUNT project has reported that de-icing chemicals can be transported by distances of up to several hundreds of metres away from the road edge by atmospheric processes. Water is also responsible for salt transportation to receiving waters through runoff and infiltration. Terrestrial plants and aquatic vegetation have the ability to take up de-icing salts. Therefore, de-icing salts exhibit temporal and spatial variation in concentration in soil, groundwater and surface waters.

The relative contributions of dry and wet aerial deposition to highway runoff pollutant loadings is not well understood whereas the percentage contributions of aerial dispersion and direct runoff have been reported (Table 2.5). The variabilities in the relative contributions will be dependent on a number of 'on-highway' processes for which further research is recommended. Factors which can influence pollutant pathways include local weather conditions (e.g. rainfall amount and intensity), traffic characteristics (e.g. traffic density and composition), topography and geo-physical conditions (e.g. relief, vegetation, and soil type), road configuration, and type of road surface and design.

Porous asphalt promotes drainage and has the capability of pollutant retention within the pores reducing the amount of polluted material available for removal. The presence of a hard shoulder increases the amount of pollutants transported via runoff as pollutants deposited in this area through the aerial route can be preferentially removed before further resuspension or splash can occur. Particles >10 µm are not expected to remain airborne for a long period of time (Vogelsang et al., 2018) whereas smaller particles can travel distances up to 50 km (Kole et al., 2017) depending on their size and density as well as local conditions (Wagner et al., 2018).

Table 2.5. Contributions of road associated pollutants to transport pathways 'aerial dispersion' and 'direct runoff'

Percentage of pollutants transferred		Selected reference
By aerial dispersion	By runoff	
46-92	8-54	Best (2003)
64	36	Boller (2006)
65	35	TRL (2002)

According to road configuration and during rainfall events, runoff can be transported by drainage systems, to a nearby adjacent surface water or allowed to discharge over the road shoulder and embankment to adjacent soils. Depending on local and hydrological conditions the soil is able to utilize its natural attenuation capacity to retard pollutants. Long term infiltration of runoff through soils is dependent on the depth to groundwater and the behaviour of the pollutants in terms of maintained solubility against adsorption to soil particles. Consideration of the physico-bio-chemical characteristics of specific pollutants can provide important information regarding their fate and should be applied more widely to assist interpretation of the behaviour of pollutants in the highway and adjacent soil environments. Intense storms after a prolonged dry period can produce an elevated runoff pollutant load, known as a 'first flush', which can exert a negative impact on the receiving water environment.

Additional processes influencing the environmental fate of pollutants include volatilisation, biodegradation and photolysis (Geissen et al., 2015). For example, benzothiazoles, which are found in road runoff due to their use as vulcanisation accelerators and/or antioxidants in tyre rubber (Avagyan et al., 2013; Unice et al., 2015), possess low log K_{ow} values characteristic of a moderately low adsorption (Matamoros et al., 2010). Similarly, photolysis is not considered to be an important removal process for benzothiazoles (Azizian et al., 2003). However, a relatively short volatilisation half-live of 30 minutes for benzothiazole (Reddy and Quinn, 1997) and a biodegradability of 74% over a period of 28 days (ECHA, 2020) indicate substantial losses from the water phase. Matamoros et al., (2010) have demonstrated a high removal efficiency for benzothiazoles from the water phase in constructed wetlands due to a combination of biodegradation and plant uptake.

2.4. Data: Measurement and Prediction

2.4.1. Measurement

The determination of the concentrations and loadings of pollutants in the highway environment is dependent on the careful collection of representative samples combined with the application of an accurate analytical methodology. Reliable proven measurement techniques are available for the majority of pollutants (including metals and organic micropollutants) but the assessment of microplastics is considerably less well established. The current status of the developments in this field are described in MICROPROOF Deliverable 1.2 (M 1.2) and are summarised in Section 2.4.1.1 below.

2.4.1.1. Measurement techniques for microplastics

Roads are a major source of tyre microplastic particles with reported tyre particles in the size ranges varying from nanometres to micrometres (Kreider et al., 2010; Dahl et al., 2006; Mathissen et al., 2011) although no single study has covered the whole size range. Analytical quantification of microplastics in tyre materials present in environmental samples remains a demanding major area of research with only a few studies reporting the measurement of microplastics in road runoff, road dust, or soils adjacent to roads and using vastly different techniques.

The most widely used methods are FT-IR spectroscopy and Raman spectroscopy but they are of limited application due to the absorption of light by carbon-black. Thermo-analytical techniques are only able to quantify the total polymer mass in the sample and not the individual particles. An alternative approach is to monitor markers, such as styrene and neoprene, using a Curie-point pyrolyzer coupled to a GC-FID (gas chromatograph – flame ionization detector). Using this technique, Saito (1989) detected styrene butadiene rubber at concentrations of 75 – 920 µg g^{-1} and neoprene from trace amounts to 1760 µg g^{-1} in Japanese road dusts. Similarly, the use of additives (e.g. 2-(4-morpholinyl)benzothiazole (24MoBT), benzothiazole (BT), 2-hydroxybenzothiazole (HOBT) and zinc) have been used to determine tyre particles in dry road dust ranging from zero to 21% (Wik and Dave, 2009). Using a pyrolysis GC-MS method, Unice et al. (2013) found concentrations of tyre wear particles in soil and sediment in the range between 26 and 11600 µg g^{-1}. Therefore, it is clear that tyre particles can be present in road dust, road runoff, and soils in the vicinity of roads and that a range of accurate analytical techniques are required to precisely determine their levels.

2.4.1.2. Emission factors for microplastics (MPs) and organic micropollutants (OMPs)

The emission factors for microplastics and organic micropollutants in relation to the sources available in the highway environment have been discussed in Section 2.2.2 and are reported in Table 2.2. The three sources which are identified as contributing to emissions of microplastics are the wear of tyres, asphalt and road markings. By far the largest emissions of microplastics are from tyres with average emission factors of 90-270 mg/vkm and reaching as high as 1500 mg/vkm for truck/commercial vehicle tyres (e.g. Klein, 2018). The reported values represent the total amount of microplastics that are released to the road surface, the adjacent soil and surface waters. No MP emission factors have been reported for brake wear, vehicle coatings and corrosion products due to the absence of sufficient data although these sources may make significant contributions to loadings and concentrations in the highway environment.

Markiewicz et al. (2017) have reviewed the emission of organic micropollutants related to traffic and road activities. The emission factors (µg/vkm) for a range of OMPs from tyres, brakes and lubricants are shown in Table 2.3. The reported emission factors cover a range of three orders of magnitude with the highest being N-(1,3-dimethylbutyl)-N'-phenyl-1,4-phenylenediamine (150 µg/vkm) and 1,3-diphenylguanidine (46.5 µg/vkm), both from tyres, and the lowest being PAH 16 (0.09 µg/vkm) from brakes.

Unfortunately, for some sources, there is no information on the exact composition of tyre material and therefore on the true nature of the emissions. Therefore it has to be accepted that the tabulated data is not complete and further investigations are still required into the emission factors of OMPs in the highway environment. Only PAH are reported consistently and in sufficient detail to enable a confident identification of tyres and lubricants as important sources.

2.4.1.3. Concentrations of microplastics (MPs), organic micropollutants (OMPs) and metals in highway runoff

There are only limited reported measurements of MPs in stormwater runoff from roads and highways. Although not focusing specifically on tyre particles, Olesen et al. (2017) have monitored MPs in the stormwater and sediments within an urban stormwater pond using FT-IR imaging. The

sediment contained 5.2 x 10^5 OMP particles/kg dry sediment (equivalent to 26 mg kg^{-1} dry sediment) and OMP particle concentrations in water samples were 1.1 x 10^2 particles/L (equivalent to 4.5 µg L^{-1}). Although concentrations of OMPs are more commonly reported in highway runoff, road dusts and soils adjacent to roads, the availability of data is limited and there is a need for more extensive measurements to enable impacts on water quality to be more reliably predicted. The concentrations of the different OMPs which have been determined in highway runoff are reported in Table 2.4 together with their major sources. Measurements of PAHs are more widely reported than for the other OMPs and this is also the case in road dust with a review by Majumdar et al. (2017) reporting concentrations typically ranging between 1 and 100 µg g^{-1} whilst temporal PAH loadings varied between 40.5 and 70.9 g/(ha year) (Lutz, 2017).

The only OMPs for which both emission factors and runoff concentrations have been reported are benzothiazole, 2-mercaptobenzothiazole, N-cyclohexyl-1,3-benzothiazol-2-amine and PAH. The limited compatibility in the availability of data for emission factors and runoff concentrations is a concern as it restricts the ability to correlate these parameters within the highway environment and to use emission factors as a guide to the occurrence and prediction of OMPs in runoff. Thus the OMP with the highest reported emission factor is N-(1,3-dimethylbutyl)-N'-phenyl-1,4-phenylenediamine (150 µg/vkm) but no runoff concentrations are currently available for this pollutant. It is recommended that in the planning of further research on OMPs, the focus should be on ensuring consistency between data on emission factors and runoff concentrations for specific substances. This would also facilitate a fuller understanding of the transfer processes of OMPs from roads to the surrounding environment.

Metals and total suspended solids (TSS) have been more extensively studied in the highway environment than OMPs. PROPER Deliverable 1.3 (P 1.3) reports their concentrations in the runoff from 22 different rural highways throughout Europe. The selected sites represent a wide range of diverse characteristics (drainage areas varying from 288 m^2 to 58,680 m^2; annual precipitation varying from 518 mm to 1014 mm; Annual Average Daily Traffic (AADT) ranging from 2,918 up to 78,000) and include 1 road from Norway (Åstebøl and Coward, 2004), 6 roads from England (Moy et al., 2003), 3 roads from Ireland (Bruen et al., 2006; Higgins, 2007), 2 roads from Switzerland (Scheiwiller, 2014; Scheiwiller, 2016), 1 road from France, 2 roads from The Netherlands (Brongers, 2010; Brongers, 2011) and 6 roads from Portugal (Barbosa and Fernandes, 2008). The monitoring data for the 6 highway sites in Portugal are shown in Table 2.6 for TSS and the metals Cu, Zn, Pb, Cd, Fe and Cr. The concentration ranges vary considerable at each site, by up to 2 orders of magnitude, indicating that a number of influencing factors exist additional to those identified at present.

2.4.1.4. New measurements of microplastics (MPs) and organic micropollutants (OMPs) in highway runoff

Because road runoff concentrations of MPs and OMPs have not been extensively measured a further study was conducted focusing on microplastics from tyre wear and 10 selected OMPs in highway runoff, in adjacent surface waters, in sediment, in road surface dusts and in soils adjacent to roads (see M6.6). The OMPs to be investigated were identified based on their inclusion as priority substances in the Water Framework Directive and/or on their RICH (Ranking and Identification of Chemical Hazards) ranking based on properties such as volatility, persistence, risk of bioaccumulation, risk of toxicity and long-term adverse effects.

Table 2.6. Road runoff pollutant concentrations from six sites in Portugal

Parameter	Road site identifier					
	A1	A2	A6	A22	A25	IP6
TSS (mg L^{-1})	1.2-100.8	0.1-5	1.6-6.3	25.7-88.0	2.2-207.3	23.8-510.0
Cu (µg L^{-1})	7.5-32.9	5.4-14.0	2.4-14.0	20.0-30.0	5.5-655.8	3.0-69.8
Zn (µg L^{-1})	21.1-277.0	40-97	46.0-1443.0		30.2-406.9	17.5-147.1

Pb (µg L^{-1})	0.9-9.0	0.1-4.1	1-4.7	10-30	6.5-69.7	1-23.4
Cd (µg L^{-1})	0.048-0.154					1-1.43
Fe (mg L^{-1})	0.01-1.90	0.1-0.12	0.08-0.77	0.7-3.3	0.04-7.35	
Cr (µg L^{-1})	0.31-15.3					3-17.0

Three European highway sites were investigated in Germany (A61), Sweden (E18) and The Netherlands (A2) (see MICROPROOF Deliverable 6.6 (M 6.6)). Although state-of-the-art analytical techniques were used, there was a lack of consistency in the types of samples collected at the different sites with road runoff only analysed at the A61 and E18 sites compared to surface water adjacent to the A2 sites. All water samples were filtered prior to OMP analysis and therefore the results are not directly comparable with previously reported data for total water concentrations. Only single samples were collected and analysed except for the German site where a mixed sample representing all the events in one month was obtained. The results of the analyses at all three highway sites are shown in Table 2.7.

Measured tyre wear concentrations in runoff of 1000 µg L^{-1} and 59,000 µg L^{-1} for the Swedish and the German sites respectively indicate a potential dilution approaching an order of 1000 when compared with the concentration of 6 µg L^{-1} found in the surface waters adjacent to the A2. The determined surface water concentration is at the lower end of the modelled concentration range for tyre road wear particles between 3.7 and 270 µg L^{-1}, with an annual average of about 120 µg L^{-1} in the surrounding sub-catchments (Unice et al., 2019).

All the selected transport related OMPs were detected in runoff except for nonylphenol, mercaptobenzothiazole and tolyltriazole with typical dilution factors of 10-1000 additionally resulting in 4-tert-octylphenol, bisphenol A and diisodecyl phthalate not being detected in surface water. The higher runoff concentrations for the German road (AADT 73,310) compared to the Swedish site (AADT 21,300) are consistent with the higher traffic flows. This is not the case for the determined PAH levels and these are also considerably lower than previously reported runoff concentrations. In the case of measurements made prior to 2010 this can be explained by the fact that a ban on the use of PAH in tyres was only operational after Directive 2005/69/EC (EU, 2005) came into force.

There is a need for microplastic concentrations and loads, arising from tyre wear, to be monitored for longer representative periods at different sites to further enhance the understanding of the distribution of tyre wear particles in the environment and to establish whether rural highways, in contrast to urban roads, are prime OMP generators. This would allow the establishment of a mass balance which could inform how tyre wear particles are released to and subsequently transported in the roadside environment. Similarly, in countries where water authorities do not monitor this, it is recommended that tyre wear microplastic determinations be extended to other surface water bodies.

Table 2.7. Concentrations in untreated highway runoff and in surface water, determined at three sites

	Filtered (0.45 µm) highway runoff concentration (µg L^{-1})		Filtered (0.45 µm) surface water concentration (µg L^{-1})
	A61	E18	A2
Microplastics (from tyre wear)	59000	1000	6.0
Benzo(a)pyrene	0.0012	0.0008	0.0001
Fluoranthene	0.0030	0.0031	0.0011
Nonylphenol	<0.01	<0.01	<0.01
4-tert-octylphenol	0.1972	0.0162	<0.01
Di(2-ethylhexyl)phthalate	0.6587	0.7196	0.9781
Bisphenol A	0.0278	0.1007	<0.01
Mercapto benzothiazole	<0.01	<0.01	<0.01
Tolyltriazole	<0.01	0.3982	<0.01
Diisodecyl phthalate	2.5752	0.6039	<0.001
Hexa(methoxymethyl)melamine	3.8921	2.1967	0.0707

2.4.2. Prediction

2.4.2.1. Prediction of concentrations of TSS, Cu, Zn, Pb and Cd in highway runoff

Six existing models for the prediction of road runoff pollutant concentrations were selected for further assessment based on their data requirements, the ease of application and the consistency of the output results. These models, which are identified below, have been fully described in PROPER Deliverable 1.2 (P1.2) and have been evaluated in order to identify the most feasible for use by operators or road designers.

- PREQUALE (Barbosa *et al*., 2011)
- Highways Agency Water Risk Assessment Tool (HAWRAT) (Crabtree *et al*., 2008)
- Multiple linear regression by Kayhanian *et al.* (2007)
- Stochastic Empirical Loading and Dilution Model (SELDM) (Granato, 2013)
- Multiple linear regression by Higgins (2007)
- Risk Assessment of road stormwater runoff (RSS) (Gardiner *et al*., 2016)

The performance of each model has been rated taking into account the required input data (e.g. site and climate characteristics; event characteristics), their applicability and the relevance of the output results (e.g. pollutant predicted; site mean concentration, event mean concentration, load). Based on this analysis, four models (PREQUALE; HAWRAT; Kayhanian *et al.* (2007); SELDM) were selected for further investigation by application to the 22 case studies identified in P1.3 to enable comparison of the predicted with monitored results (see PROPER Deliverable 1.4 (P1.4)). PREQUALE was found to be the most straightforward model to use through a relatively simple equation for which all the required data was easily available. Although the application of HAWRAT was simple for sites located in the UK, using meteorological data already included in the software, for other countries hourly precipitation time series were needed to calculate all parameters and derive predicted pollutant concentrations. Similar problems were encountered during the implementation of SELDM making its use outside the USA complicated because of the need for several precipitation statistics. The four tools require different processes for their implementation.

SELDM has a graphical interface and all calculations are performed in the software. PREQUALE uses a simple equation whereas HAWRAT and the equations proposed in Kayhanian et al. (2007) were implemented in Excel spreadsheets. PREQUALE predicts site mean concentrations (SMCs) whereas the other models determine event mean concentrations (EMCs). Where SMCs were not directly predicted they were obtained by averaging the EMCs and are plotted against the concentrations obtained by monitoring in Figure 2.5 for TSS, Cu, Zn, Pb and Cd.

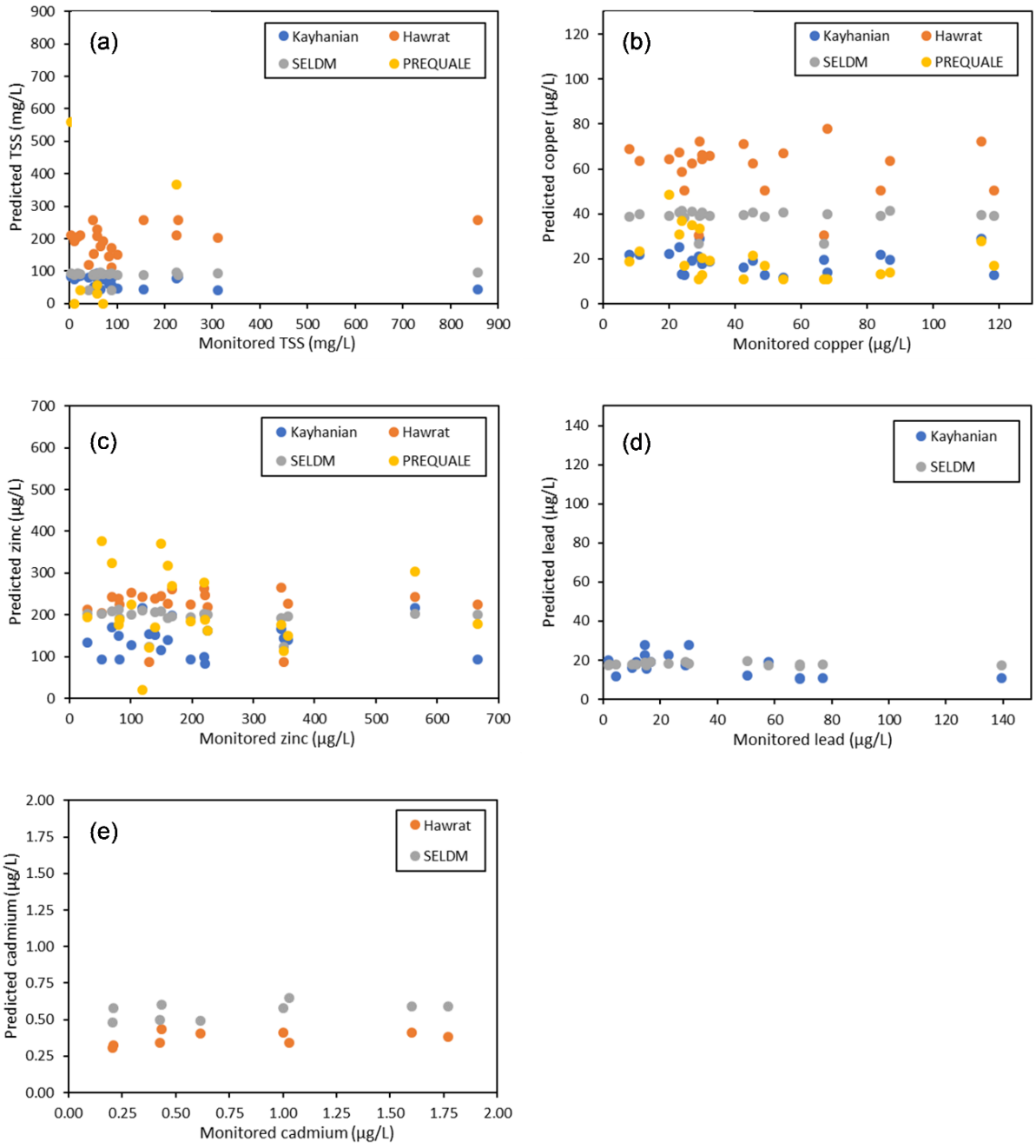

Figure 2.5. Comparison monitored and predicted SMC values for (a) TSS; (b) Cu; (c) Zn; (d) Pb and (e) Cd

Inspection of Figure 2.5 clearly shows that the tools are not able to accurately predict the concentrations of all five pollutants. Compared to the monitored data, the predicted values consistently show little variability across the different case study sites indicating negligible

sensitivity to the input values for all four tested tools. Regression analysis identifies the existence of low R^2 values (ranging from 0.0004 and 0.2890) confirming the visual observation that no linear relationship exists between the predicted and monitored values.. Existing models, which have been calibrated and validated for a given site, region or country, are therefore not able to be widely used and are not recommended particularly outside the site/region for which they have been calibrated without the necessary modification. The alternative is to investigate other approaches for the prediction of pollutant runoff concentrations with one possibility being through the use of pollutant emission factors and which may be more appropriate for evaluating proposed highway projects. The development and application of emission models is described in PROPER Deliverable 1.5 (P1.5) (see Section 2.4.2.2) with the outputs being usable in runoff models to assist in runoff calculations and potentially improve the correlation between the actual and modelled runoff concentrations.

2.4.2.2. Emission models and air quality assessment models

The range of regional and national scale models which are available for emission calculations and air quality predictions are reviewed in PROPER Deliverable 1.5 (P1.5). Emission models are used to predict the pollutant load which is potentially available to surface waters. They specifically focus on tyre, brake and road wear which produce relatively large particles that are deposited in the vicinity of the road. In contrast, exhaust emission particles are relatively small and remain suspended in the atmosphere for longer periods allowing transport further away from roads. In addition to detailed traffic characteristics, emission models rely on accurate emission factors. These are dependent on national and local circumstances (types of vehicles, types of roads, speed limits, braking and steering patterns, etc.), and therefore an average country-specific emission factor is not necessarily useful for other countries.

A software application which is widely used throughout Europe to model emissions from road traffic is COPERT (COmputer Program to calculate Emissions from Road Transport) (COPERT 5, 2016). This model uses road transport emission factors developed according to the European methodology described in the EMEP/EEA Guidebook (EMEP/EEA, 2016). Country specific models differing in the detail of the input and output data have been developed in the Czech Republic (the CDV and MEFA emission models), jointly in Germany, Switzerland and Austria (HBEFA emission model) and in The Netherlands. The range of pollutants assessed by these models can be extensive but typically includes NOx, PM, CO, NMVOC, NH_3, PAH and metals.

Those road related pollutants, which are transported away from the road by atmospheric processes, may eventually enter the soil body or a surface water body through dispersion and deposition processes. Air quality models utilise physical atmospheric processes to model dispersion and deposition and several have the ability to predict atmospheric concentrations and compare these to air quality standards and limit values. They can also contribute to the development of air quality improvement plans at various scales from street level hotspots to urban areas and rural road networks. Examples of established European air quality models include ADMS (Atmospheric Dispersion Modelling System) Urban (CERC, 2013), OSPM (Operational Street Pollution Model), the Czech model SYMOS ’97 and the Dutch model (NNM). The dispersion and deposition of particulate matter depends on particle sizes, meteorological circumstances and land use.

The NNM model has been applied to the downward transport of wear emissions in the vicinity of a hypothetical highway consisting of two lanes and an emergency lane, and having an AADT of 30,000 vehicles per day (see P1.5). The emphasis was on the larger particles (released by tyre, brake and road wear), that are expected to deposit near the road and not on the smaller exhaust emissions. Resuspension via air was found to represent the largest emission contribution to the total deposition followed by resuspension via splash and spray which is limited to wet weather

conditions. Similar contributions were predicted to occur as a result of surface, tyre and brake wear.

2.4.2.3. Prediction of surface water concentrations of microplastics and organic micropollutants

A first order estimation procedure has been proposed for predicting potential surface water concentrations of microplastics and OMPs based on a theoretical dilution of reported runoff concentrations (MICROPROOF Deliverable 2.2 (M2.2). A dilution factor of 100 has been assumed leading to predicted surface water concentrations for fluoranthene and benzo(a)pyrene of 36.49 µg L^{-1} and 8.29 µg L^{-1} based on stormwater concentrations reported by Tromp (2005). Where the concentrations in sediment of storm water treatment systems are known, the same dilution factor is recommended for predicting surface water sediment concentrations. When this value is not available, it is suggested that a fixed dilution ratio of 10 between the storm water concentration (µg L^{-1}) and sediment concentration (µg g^{-1}) is applied as reported for a selection of pollutants by Björklund et al. (2009). It is accepted that the uncertainties in the predicted environmental concentrations will be large, partly due to the limited data availability but also because of the dilution factor approximations. The lack of data is particularly relevant for microplastics derived from tyre wear where dependence on modelled data (Unice et al., 2019) suggests concentrations in surface waters within a range between 3.7 and 120 µg L^{-1}. The dangers of using generalised relationships for predicting surface water concentrations can be illustrated by reference to the data presented in Table 2.8 (extracted from M6.6) showing comparisons with measured concentrations where these are above detection limits. The predicted MP concentrations consistently exceed measured values whereas different OMPs can be either lower or higher than measured levels by at least an order of magnitude.

Table 2.8. Comparison of predicted and measured water concentrations and suspended sediment concentrations in surface waters (MICROPROOF Deliverable 6.6. (M6.6))

	Water concentrations (ng L^{-1})		Suspended solid concentrations (ng kg^{-1})		WFD AA EQS (µg L^{-1})
	Measured	Predicted	Measured	Predicted	
Microplastics	6.0 x 10^3	120 x 10^3	300 x 10^3	1200 x 10^3	
Benzo(a)pyrene	0.1	8.29	7.34; 23.9	82.9	0.05
Fluoranthene	1.1	36.5	16.7; 45.2	36.5	0.1
Nonylphenol	bdl	3.6	20.8; 1.1	31.0	0.3
Di(2-ethylhexyl)phthalate	978.1	22.7	10.3 x 10^3; 14.3 x 10^3	980.0	1.3
Mercapto benzothiazole	bdl	1.1	2.3	11.0	
Tolyl triazole	bdl	23.0	5.8; 6.4	230.0	
Disodecyl phthalate	bdl	86.0	1970.9; 650.2	860.0	
Hexa(methoxymethyl) melamine	70.7	8.8	bdl	88.0	

bdl = below detection limit

2.5. Receptors and Impacts

2.5.1. Impacts on surface water quality

Highway runoff can impact negatively on the chemical status of receiving waters (P2.1). Several surface water studies have reported on a wide range of physico-chemical parameters (including pH, temperature, COD, BOD, NH_3, TSS, hardness, DO, organic compounds, metals and chlorides) in waters receiving highway discharges (Moy et al., 2003; Swadener et al., 2014; Meland et al., 2010a, b) whereas others concentrate on metals (e.g. Kayhanian et al., 2008; Perdikaki and Mason, 1999) or PAHs (Grung et al., 2016; Adamec et al., 2004). Water pollution by both PAHs and metals has been reported by Beránkova et al. (2008) and Beránkova et al. (2010) (P2.4). Elevated concentrations in receiving waters were most commonly observed for

chlorides, which are released into water courses mainly in winter from de-icing agents due to winter road maintenance (L2.1) and may have a negative influence on aquatic invertebrates (Corsi et al., 2010; Williams et al., 1999; Blasius and Merritt, 2002). As indicated in Table 2.8 a number of potentially toxic micropollutants currently have no quantified EQS values under the EU WFD (EC, 2019)

2.5.2. Impacts on groundwater quality

Groundwater quality could potentially be jeopardised by both direct (infiltration of runoff via BMPs/SuDS) and indirect (leaching of pollutants from soils) processes. During direct infiltration, there is little evidence of the mobilisation and/or downward transfer of pollutants, such as metals, from contaminated basal sediments (P2.1). However, the more soluble pollutants, such as chloride present in de-icing materials, can be more rapidly transferred to the shallow unsaturated zone (P2.1) (Rivett et al., 2016; Howard et al., 1993). For example, in the Toronto area between 40 and 55% of the chloride applied annually has been found to infiltrate to the local aquifers (Howard et al., 1993; Perera et al., 2013). Rivett et al. (2016) identified winter discharges of salt to be a significant source of chloride for aquifers with evidence for exceedance of 250 mg/L (EQS for surface waters) and this may be the norm for some member states such as Finland. However, the relationship between road salt concentrations and environmental response is non-linear as, whilst adverse effects on roadside vegetation and aquatic life are observed in nearly all studies, the types of effects, effect concentrations and magnitudes of impact vary both between species and as a function of water body characteristics (L2.1). Knowledge gaps, which need to be addressed to limit chloriide build-up in aquifers, include the fate of NaCl in the soils and the transport of road salts over greater distances via air or groundwater.

2.5.3. Impacts on receiving water biota

Highway runoff may impact negatively on the ecological status of receiving waters as evidenced by differences in species composition, abundance and feeding behaviour. Impacts (varying from impact on gene expression to mortality) on aquatic species have been reported for a range of fish species (e.g. Hurle et al. 2006), frogs and different tadpole life-stages (Meland et al., 2013), tadpoles, dragonflies and plants (Grung et al., 2016) and macroinvertebrates (P2.1) (e.g. Maltby et al., 1995). For example, using a battery of bioassays involving daphnia, bacteria and fish, Mayer et al. (2011) found that *Daphnia magna* and *Ceriodaphnia dubia* were sensitive to increasing concentrations of chlorides and metals in highway runoff. Corsi et al. (2010) found high concentrations of chlorides to be toxic to *Ceriodaphnia dubia* and *Pimephales promelas*. G*ammarus* (Amphipoda) have been shown to be affected by chloride concentrations greater than 5000 mg L^{-1} over a 24 h exposure period (Blasius and Merritt, 2002). There is also evidence of a first flush effect with runoff toxicity decreasing during storm events (Mayer et al., 2011, Kayhanian et al., 2008). It is important to note that studies also exist which report no toxicity associated with road runoff (e.g. Swadener et al., 2014, Adamec et al., 2004). Bioaccumulation studies have evaluated the accumulation of metals (Perdikaki and Mason, 1999, Yousef et al., 1984) and PAHs (Grung et al., 2016, Baekken, 1994, Meland et al., 2010b) in aquatic plants and organisms exposed to highway runoff. Pollutant concentrations above background levels have been observed for Cd and Zn in bivalves, Pb in perch liver and PAH in perch flesh (Baekken, 1994). Similarly, Meland et al. (2010b) have reported the accumulation of trace elements in the gills of fish. But there are other instances where the ecology of surface waters downstream of a highway discharge site does not significantly differ from that upstream (e.g. Bruen et al., 2006). Thus the establishment of a causal relationship is not clear cut. Therefore, more investigations need to be directed towards understanding magnitude and frequency of pollutant loads in highway discharges which limit the continued survival of existing ecosystems. This could be assisted by a more thorough integration of both population/community techniques with analytical chemistry determinations. Whilst acute ecological impacts are well described, relatively little is understood

of the response of receiving water ecologies to repeated, low level (chronic) exposures to highway drainage in order to more accurately define lowest chronic toxicity limits.

2.5.4. Receptor vulnerability

The development of a common definition of the term 'vulnerable water body' needs to consider the inherent characteristics of the receiving water (i.e. its hydrology, hydrogeology and chemical and ecological status) and the influence of anthropogenic activities e.g. road construction and operation. An overview of the aspects identified as influencing the vulnerability of receiving waters is presented in Table 2.9. providing a summary of the impacts and associated vulnerabilities arising from the discharge of highway runoff to receiving waters (P2.2). As the influence of these factors can change, according to the circumstances, Table 2.9 contains comments on the nature of receiving water impacts, and a score is allocated to each impact on a scale of -5 to 5. A negative score indicates the parameter has the potential to increase the vulnerability of the receiving water whereas a positive score signifies the ability to reduce this vulnerability. Because it is possible for several site specific conditions to influence the direction of impact, the net result will be determined by a balance between the magnitude of the negative and positive values.

In PROPER Deliverable 2.1 (P2.1), receiving water vulnerability was defined as a function of the inherent bio-physico-chemical characteristics of a waterbody. PROPER Deliverable 2.2 (P2.2) identifies receiving water characteristics which can contribute to making one waterbody more (or less) vulnerable to the same inlet pollutant loading in comparison with another. This assessment is the basis for the development of a standalone tool to support the systematic identification of the relative vulnerability of receiving waters to highway discharges (P2.5). To support development of a user-friendly tool, the 14 surface water and ten groundwater vulnerability indicators identified in P2.2 were reduced and, where feasible, integrated into a short-list of 11 indicators. Surface water indicators were short-listed by selecting parameters identified as having comparatively the greatest impact with regard to receiving water vulnerability (i.e. scored ≤ -2 or ≥ 2). Occurrence of an indicator in both the DRASTIC and DMRB models (both used to map receiving groundwater vulnerability) was used as the basis for shortlisting indicators to assess receiving groundwater vulnerability (full details are provided in P2.2). Following the identification of a short-list of indicators, the next stage of the vulnerability assessment involved developing an approach for benchmarking each indicator. In keeping with a need to develop a screening tool that may be applied within a range of Member States and climates, a primarily qualitative approach to benchmarking receiving water vulnerability indicators was adopted. Qualitative assessment uses a relative scale where numeric values are pre-defined to represent a comparatively escalating likelihood of occurrence, such as that presented below:

- Likely (expected to occur): score of 4
- Possible (may occur sometimes): score of 3
- Unlikely (uncommon but known to occur): score of 2
- Rare (lack of evidence but not impossible); score of 1

The use of such a qualitative approach is well recognised and globally accepted (e.g. DEFRA, 2011; Elgallel *et al.,* 2016). As an example of the application of this approach, Table 2.10 identifies shortlisted groundwater vulnerability criteria, supporting indicators and descriptors (which specify the particular aspect under consideration), together with example benchmarking and scoring schemes. The resulting qualitative framework supports the systematic identification of receiving water vulnerability to polluted discharges (P2.5).

Table 2.9. Summary of the impacts and associated vulnerabilities arising from the discharge of highway runoff to receiving waters (P2.2)

Type of impact	Influencing factor	Nature of receiving water impact	Observation	Score
Geological	Natural weathering of rocks and soils	Provides essential minerals and nutrients	Contributes to maintaining the health of aquatic ecosystems	+1
Hydrological	Increased flows	Changes to pool riffle sequences	Reduction in receiving water habitats	-2
	Scouring of basal sediments	Increased mobilisation and transport of sediments with a shift from coarse to fine sediment distribution	Loss of channel diversity due to channel migration, degraded habitat quality; inhibition of aquatic plant, macroinvertebrate and fish growth (loss of spawning sites)	-2
	Enhanced dilution capacity	Potential to reduce pollutant levels below toxic thresholds	Protection of sensitive biota	+3
	First flush effect	Possibility of high pollutant loads being delivered to receiving water during early stages of a storm event (particularly after long dry periods)	Elevated levels of toxicity during initial stages of a storm event	-3
Chemical	Increased total suspended solids levels in runoff	Particulates (particularly those enriched in organic material) acts as sites for both metal and PAH sorption	Possible small reduction in toxicity due to pollutant adsorption balanced by increased turbidity (habitat degradation) and biotic impacts e.g. irritation to fish gills	0
	Elevated chloride concentrations in runoff due to winter maintenance activities	a) Aquatic biota demonstrate different sensitivities to high salt levels b) Chlorides facilitate the release of metals from solid to soluble phase due to ion exchange processes and formation of chloro-complexes c) Increased ionic strength can mobilise dissolved organic carbon from solid phase and associated release of PAH to soluble phase	Encouragement of drift behaviour and possibility of toxic impact Increased toxicity Increased toxicity	-4
	Receiving stream water hardness	Ca and Mg ions compete with metal pollutants for membrane binding sites in aquatic organisms	Reduction in metal bioavailability and toxicity	+2
	Receiving stream alkalinity	Removal of free metal ions due to carbonate complexation	Reduction in metal bioavailability and toxicity	+1
	Naturally occurring organic materials in receiving water	a) Removal of free metal ions due to organic complexation b) Mobilisation of hydrophobic PAHs previously preferentially attached to particulates	Reduction in metal bioavailability and toxicity Potential increases in PAH bioavailability and toxicity	0
	Receiving stream acidity	Promotes availability of free metal ions; some competition between metal and hydrogen ions for cell surface adsorption sites	Increase in metal toxicity balanced by some competitive uptake.	-1
Ecological	Elevated runoff temperatures	Influences physiological processes; reduces dissolved oxygen levels and possibly increases concentrations of dissolved substances	Affects the metabolic and reproductive rates of algae, benthic invertebrates and fish	-2
	Physiological stress due to water quality	Species sensitivity	Different species and different life stages show different responses	-2
	Physical presence of roads	a) Provide movement corridors and changes to stream habitats b) Separation of streams from flood plains	Changes in species composition Limitation of exchanges between stream and riparian zone	-1
	Factors influencing food availability	Affects the distribution of different aquatic species	Possible reductions in biodiversity	-1

Table 2.10. Characteristics which inform about the vulnerability of receiving groundwater and an indication of how these could be benchmarked and scored (P2.5)

Criteria	Indicator	Benchmark	Score	Weighting
Aquifer media	Permeable (and fractured) rock materials render aquifer more vulnerable	Karst / chalk	1	2
		Sand / gravel	2	
		Metamorphic / igneous	3	
		Clay / shale	4	
Permeability / depth of the unsaturated zone (integrates depth to groundwater)	High permeability (e.g. sand/gravel)	0 – 3.0m	1	4
		>3.0m	4	
	Moderate permeability (e.g. Glacial till, loam)	0 – 3.0m	1	
		3.0 – 10.0m	2	
		>10.0m	4	
	Low permeability (e.g. clay silt, clay, peat)	0 – 3.0m	1	
		3.0 – 5.0m	2	
		5.0 – 10.0m	3	
		>10.0m	4	

2.5.5. Environmental risk assessment (ERA) based on OMPs

Using both data from the literature and new experimental data, a shortlist of 11 OMPs (including microplastics) emitted from a range of traffic-related sources including tyres, brakes, car body coatings and road markings have been assessed using an ERA process (M3.1). This involved the comparison of substance specific predicted environmental concentrations (PECs) with predicted no effect concentrations (PNECs) with the resulting PEC/PNEC ratio being used to determine if there is a potential risk to receiving waters using deterministic (risk characterisation) and, where data permits, probabilistic (risk quantification) approaches (M3.1).

The results of the ERAs indicate that the risks to receiving water ecology from the majority of studied OMPs transported in road runoff are within acceptable limits (i.e. a risk characterisation ratio <1). However, the level of risk varies in relation to the data set used, on occasion by up to three orders of magnitude. For example, surface water PECs drawn from the literature and from Swedish and German studies indicate risks for both benzo(a)pyrene and fluoranthene in surface waters, whilst the use of monitoring data from a Dutch road side river study indicate unacceptable effects are unlikely. For OMPs in road runoff, a potential for unacceptable risk was identified for benzo(a)pyrene, 4-tert-octylphenol and diisodecyl phthalate. With regards to sediments, risks were identified for fluoranthene, 4-tert-octylphenol, bisphenol A, mercaptobenzothiazole, tolyltriazole and diisodecyl phthalate in the solid phase. With regard to analysis of microplastics, this is an emerging science with many challenges still to be addressed including the lack of standardised protocols for sampling, sample preparation and analysis. Hence, whilst application of the standard ERA approach indicates that the concentrations of microplastics in road environments pose unacceptable levels of risk to receiving water and sediment biota, these results should be interpreted with care due to the high levels of uncertainty associated with PEC values and the heterogeneity of the tested microplastics used for PNEC derivation considering polymer type, size and shape (see Tables 2.11 and 2.12) as well as the type/age of organism tested. Using a probabilistic approach, both literature-derived values and field measurements indicate that surface water concentrations of benzo(a)pyrene, fluoranthene and di(2-ethylhexyl)phthalate pose an unacceptable level of risk to receiving water ecologies. Within road runoff samples, concentrations of 4-tert-octylphenol and di(2-ethylhexyl)phthalate may also pose an unacceptable level of risk (see Table 2.11).

Table 2.11. PEC/PNEC ratios of selected substances in water (dissolved fraction) based on rough estimates for exposure (see also M2.2 and M6.6)

	PEC/PNEC ratio			
	Estimated exposure	Measured exposure		
Pollutant	Surface water	Runoff, Germany	Runoff, Sweden	Surface water, the Netherlands
Microplastics#	(363.64)	(177273)	(2955)	(18)
Benzo(a)pyrene	(48.765)	(6.923)	(4.7702)	0.6250
Fluoranthene	(5.7921)	0.469	0.4858	0.1775
Nonylphenol	0.0120	0.033	<0.0333	<0.0333
4-tert-octylphenol	0.0060	(1.972)	0.1622	<0.1000
Di(2-ethylhexyl)phthalate	0.0175	0.507	0.5535	0.7524
Bisphenol A	0.0037	0.019	0.0671	<0.0067
Mercaptobenzothiazole	0.0003	0.003	<0.0025	<0.0025
Tolyltriazole	0.0029	0.001	0.0498	<0.0013
Diisodecyl phthalate	0.1433	(4.292)	(1.0065)	<0.0017
Hexa(methoxymethyl) melamine	0.0002	0.072	0.0407	0.0013

It should be noted that the PEC for microplastics has high uncertainty and the PNEC for microplastics has a limited reliability due to heterogeneity of the tested microplastic considering polymer type, size and shape.
PEC/PNEC ratios higher than 1 (in brackets) indicates that unacceptable effects on organisms are not unlikely to occur

Table 2.12. PEC/PNEC ratios of selected substances in sediment and solids based on rough estimates for exposure (see also M2.2 and M6.6)

	Estimated exposure	Measured exposure			
Pollutant	Sediment	Runoff, Germany (solids)	Runoff, Sweden (sludge)	Surface water, river Rhine, the Netherlands (solids)	Surface water, waterway, the Netherlands (sediment)
Microplastics#	(12000)	(1500000)	(130000)	(3000)	(3000)
Benzo(a)pyrene	0.0453	0.515	0.1145	0.130	0.0401
Fluoranthene	0.1825	(1.207)	0.1511	0.226	0.0833
Nonylphenol	0.0067	0.0002	0.0002	0.0002	0.0045
4-tert-octylphenol	(3.7297)	(908)	(329)	(2.611)	0.6250
Di(2-ethylhexyl)phthalate	0.0098	0.654	0.0244	0.143	0.1027
Bisphenol A	0.8730	(3.865)	0.8850	0.084	0.0159
Mercaptobenzothiazole	0.0748	(6.872)	(1.287)	0.001	0.0158
Tolyltriazole	(76.667)	(366)	(13.143)	(2.135)	(1.9449)
Diisodecyl phthalate	0.2606	(42)	(1.397)	0.197	0.5972
Hexa(methoxymethyl) melamine	0.6617	0.244	0.0127	0.008	0.0075

It should be noted that the PEC for microplastics has high uncertainty and the PNEC for microplastics has a low reliability due to heterogeneity of the tested microplastic considering polymer type, size and shape PEC/PNEC ratios higher than 1 (in brackets) indicates that unacceptable effects on organisms are not unlikely to occur

2.5.6. Legislation relating to the management of receiving waters and highway activities

With regard to identifying EU environmental legal constraints when planning, constructing and operating a highway, Figure 2.6 presents a flowchart linking Directives to pertinent highway design/delivery aspects within a risk assessment framework. It should also be noted that in Ireland the Birds and Habitats Directives are of critical importance with planning, constructing and maintaining national roads and thus Figure 2.6 may not be fully appropriate to Ireland. Implementation of the flow chart within a GIS platform enables the use of standardised data layers e.g. those available from the EU WISE platform, allowing a visual interpretation of the responses to each of the questions listed in the flowchart for subsequent use within a risk assessment context (P2.3).

2.6. Treatment and Management

2.6.1. "Blue-green" treatment systems for pollutant removal

The adoption of a generic approach which considers pollutant properties and their behaviour under operating unit processes (OUP) (Vollertsen et al., 2012; Scholes et al., 2008) in terms of potentially effective treatment, can provide a pragmatic methodological approach to the identification and selection of appropriate SuDS/BMP options (P3.1, P3.2). The approach considers pollutant properties and their behaviour during operational treatment conditions involving particle coagulation and retention, sedimentation, filtration, sorption, biodegradation and plant uptake. Nevertheless, only generally empirical expressions or guidelines, such as surface or volumetric loadings can be derived from the treatment analysis. The OUP approach emphasises treatment solutions to reduce annual loads discharging from SuDS/BMP controls rather than single event peak concentrations. In this respect, the "blue-green" OUP approach contributes primarily to the mitigation of long term chronic receiving waterbody impact rather than short term acute impact.

The most efficient and effective systems tend to be those that filter runoff at source and are able to reduce TSS, metals and PAH levels down to near ambient background levels (Fronczyk, 2017; ilu AG, 2016; Vollertsen et al., 2018). The overall SuDS/BMP efficiency is therefore a prime function of the soil matrix, the runoff water and pollutant characteristics with low hydraulic conductivity and surface loading offering the most effective performance conditions. These conditions are best met by direct source infiltration into the adjacent roadside or central verges (Bolvin et al., 2008). This is common practice in Switzerland, Germany and Sweden (Piguet et al., 2009; Werkenthin et al., 2016). However, it must be noted that it is not possible to state that one type of treatment system will be necessarily better than another in terms of performance efficiency as this depends on factors such as size and design parameters as well as on pollutant and hydraulic loadings in addition to inherent pollutant properties and storm event characteristics. The characteristic inflow-outflow and pollutant variability associated with episodic highway runoff means that it is virtually impossible to accurately predict an EMC or SMC for a specific control site other than as a "most probable value" for a cohort of sites having similar characteristics (Madarang and Kang, 2014; Hvitved-Jacobsen et al., 2010). The greatest efficiencies tend to be associated with high inlet concentrations but there is a considerable data scatter which means that it is difficult to compare the relative site efficiencies of differing SuDS/BMP options such as retention/detention and wetland systems. Decentralised infiltration-based treatment systems are recommended (P3.1) as first-choice SuDS/BMP solutions. Such solutions need to be located as close to the pollution source as possible, which for most site locations means the median strip or adjacent roadside verge and embankment. This can involve swales and infiltration trenches/basins (with or without artificial media) but where such systems are not an option due to space and/or safety constraints, more centralised filtration systems such as bio-retention and wetland basins are recommended in comparison to less effective detention-based drainage controls.

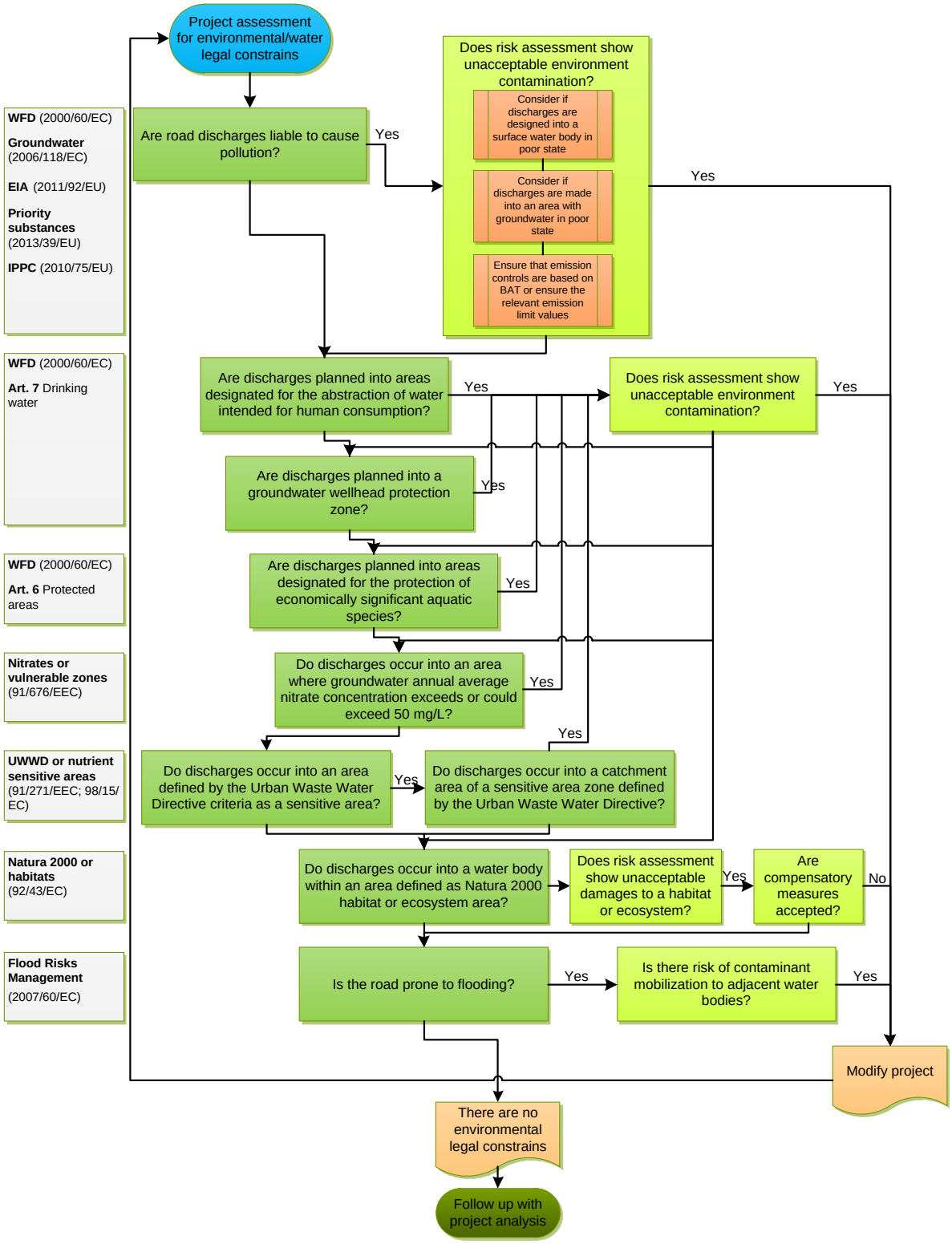

Figure 2.6. Flowchart for the assessment of a road project taking into account the relevant EU environmental legal constraints (P2.3).

There is acknowledgement in the literature that fundamental differences exist between approaches to and the design of SuDS/BMP controls in warm temperate/semi-tropical biomes (e.g. Australia, southern US and Europe) and cold climate regimes (e.g. Norway, Sweden,

Canada). The review (P3.1) confirms the availability of a large SuDS/BMP guidance literature relating to the design, operation and treatment of highway runoff. Whilst many countries still derive their design and operational practice from generic urban runoff guidance manuals, the increasing experience of highway site conditions and constraints is leading to the widespread emergence of road specific treatment guidelines. The principal driver in this emerging development appears to be the growth in environmental legislation and standards e.g. NDPES/TMDL regulations in the US or WFD regulations in Europe. However, unlike urban runoff controls which are frequently promoted by local 'bottom-up' community pressures and multi-party collaborative groups, highway treatment systems essentially originate from focussed 'top-level' decision-making and agency actions, which often have a more institutionalised approach in terms of organisation, administrative and design planning procedures. There is little evidence that highway authorities commonly consider the role of highway SuDS/BMPs in the wider catchment and regional perspective, although there is movement towards such 'blue-green' strategic integrating concepts coming from Australia, Germany and some US and UK practice. However, it is noticeable that the design emphasis is normally firmly based on engineering criteria and standards in regard to the factors influencing highway drainage and runoff treatment. The explicit adoption of engineering consistency and compliance standards as the required working criteria may not be fully compatible with the achievement of truly sustainable drainage and water management which favours a more collaborative ecological and community oriented approach (P3.2).

Grass verges and filter strips, roadside filter drains and/or grassed bioswales combined with wet detention or wetland cells (often with sediment forebays) represent common hybrid highway control options in many countries especially in areas having high groundwater conditions. Infiltration measures are commonly only recommended after sediment pre-treatment and where site-specific conditions (such as soil infiltration rate) can ensure an effective quality control. Nevertheless, there is a growing and widespread appreciation in highway drainage design for the increased implementation of on or near-roadside mitigation controls. In karstic areas such as Slovenia and Ireland, there may not be any alternative to source infiltration for highway discharges. Many countries assert that much more research and operational site experience is necessary before many national or provincial/state highway authorities are likely to adopt infiltration (or proprietary) systems on any major scale for open non-urban highway situations. However, there is little evidence that manufactured proprietary devices offer any performance or cost advantage over structural SuDS controls particularly for non-urban highway conditions.

Many national guidance manuals recommend that future highway drainage design should incorporate the potential effects of an expected 10%–15% increase in rainfall-runoff consequent upon predicted climate change by the 2050's. It is argued that the initial 5 mm of runoff should be retained for water quality control (based on a 80 – 95% solids capture) as determined by equivalence to the drained paved area for the 1:100 storm event together with climate control upraise. Most international highway design guidance still seeks the prime objective of maximum allowable flow rates as opposed to pollutant removal targets. Peak flow control may well be justified for flood management with regulated outflow rates, but in terms of water quality performance this guidance provides a very limited evidence-base. Specified SuDS/BMP quality performance criteria and standards are infrequently considered.

Transportation agencies world-wide represent essentially semi-autonomous administrative organisations and are principally motivated by legislation and regulation which are frequently regarded as being the main driving criteria in terms of engineering design. However, there is a growing awareness that SuDS/BMPs can be regarded as comprising component elements in a wider Green Infrastructure (GI) or Low Impact Development (LID) stormwater management strategy (or design with nature approach) rather than simply being viewed as an end control objective in themselves. Nordic states possess highway drainage policies which are essentially multi-functional, integrating volume and quality control with aesthetics, amenity and community acceptance (Trafikverket, 2011; NSRA, 2018). The development of multiple use eco-corridors helps to address the issue of larger drainage capacity through the provision of linear vegetated buffer strips, swales, detention/retention storage and wetlands. The step-up to full multi-functional,

multi-party involvement will not be easy to achieve as many highway agencies have little tradition and limited working experience of multi-party collaboration particularly where it involves public participation. However, this is important if sustainable management of the volume and quality of highway drainage is to be achieved in conjunction with the implementation of appropriate landscape and receiving water ecological requirements.

2.6.2. A decision support system based on SuDS/BMP treatment performance

The development of a generic spreadsheet-based matrix approach for the selection of appropriate individual SuDS/BMP treatment options for site highway runoff control is described in PROPER Deliverable 3.3 (P3.3). The methodology is specifically intended to consider options for the disposal and treatment of highway runoff. The proposed DST does not consider special site situations such as drainage into embankments, cuttings or where elevated groundwater conditions prevail. In addition, the DST is restricted to those SUDS options identified in the UK SUDS Manual. The first stage involves a site screening operation to establish the prevailing site conditions which are able to influence the suitability of a particular SUDs/BMP being installed and being able to efficiently reduce the impact of the incoming highway runoff. As shown in Figure 2.7 the required basic site characteristics include catchment size, depth and type of groundwater, soil type and annual traffic volumes. The screen shot from the Decision Support System User Guide (PROPER Deliverable 3.4; P3.4) shows the five site screening characteristics outlined in blue, each of which can be changed by clicking on the appropriate highlighted box via a drop down menu showing the options available. In the illustrated example, the site is identified as being in a loam soil area above a sensitive groundwater (categorised as Source Zone I) at a depth of between 0.6 m and 1.0 m below the treatment system. The effective contributing drainage area is less than 10,000 m^2 with a vehicle flow rate on the highway of between 50,000 and 100,000 vehicles/day. The results produced by this combination of site criteria are also shown in Figure 2.7 indicating that all treatment systems are unsuitable for use (red background colour) except for retention ponds, detention basins, extended detention basins and constructed wetlands which are considered suitable subject to advisement (amber background colour).

The developed Excel based matrix quantitatively defines six controlling performance criteria which, in turn, are benchmarked by eleven diagnostic indicators. These are identified in the first and third columns of the Excel file matrix (Figure 2 8). Each of the six functional criteria and eleven indicators are allocated default weightings (second and fourth columns) with the weightings for the Environmental indicators further sub-divided according to whether the receptor is surface water or groundwater. Twelve different SuDS/BMP controls are scored on a utility scale of 1 to 5 with a score of 5 reflecting the highest level of servicing and/or protection in respect of the control satisfying the objective criteria and indicator benchmark. The procedures by which the utility scores have been awarded are fully described in the Decision Support System Technical Manual (PROPER Deliverable 3.5; P3.5). Total scores for each SuDS/BMP are derived by the sum of the individual scores multiplied by the allocated weights. The DSS matrix outputs a histogram plot of the summed total scores for the different SuDS/BMP thereby providing a relative selection preference at the selected site (Figure 2.9). The colours of the histograms identify those drainage systems which are deemed acceptable by the methodology (shown in green), those deemed acceptable with advisement (shown in amber) and those that are deemed unacceptable (shown in red). The histogram plot shown in Figure 2.9 shows the results of applying the Decision Support System to predict the suitability of different treatment systems at a site adjacent to the UK M1 motorway near Luton.

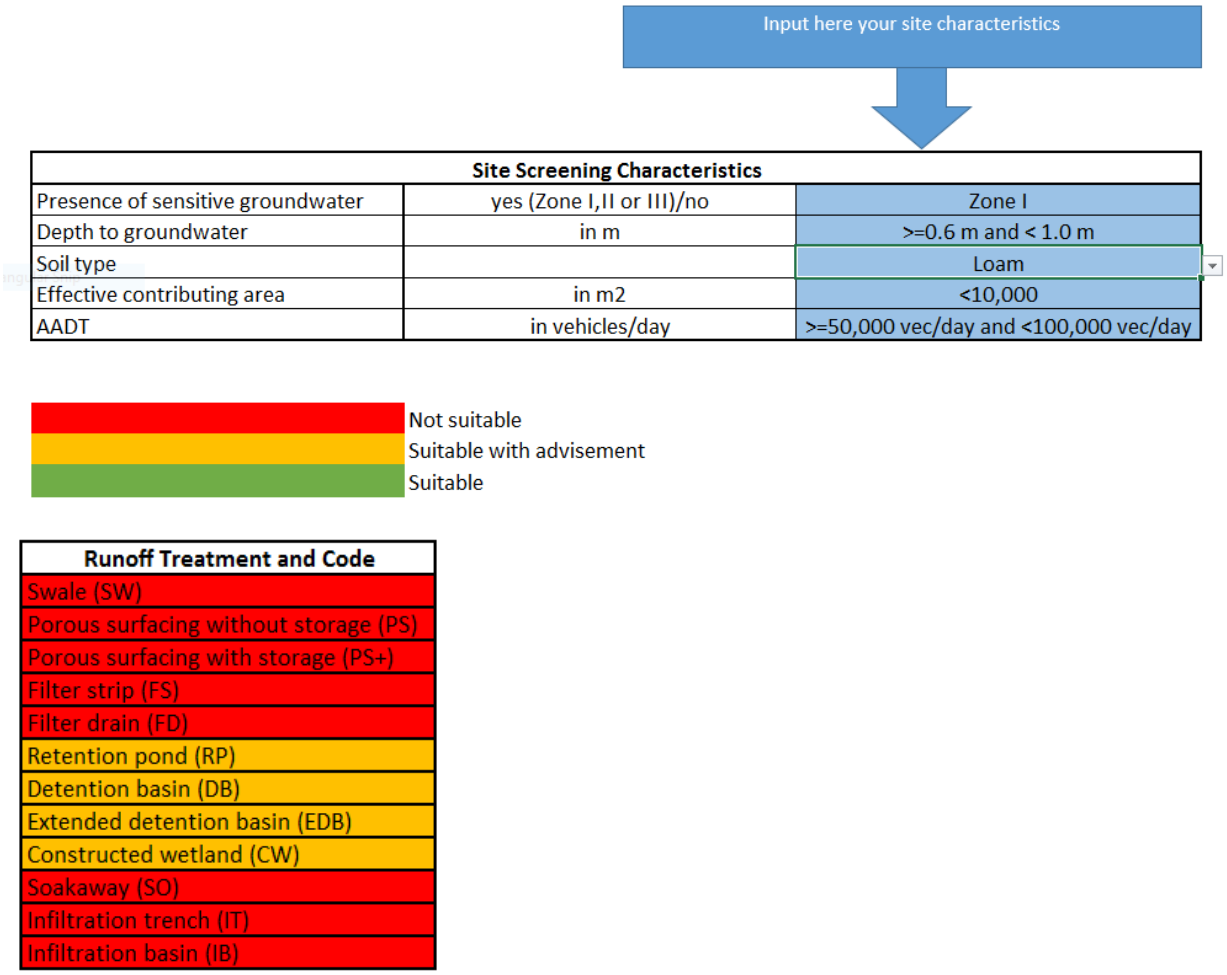

Figure 2.7. Screen shot of the 'Site Criteria' page in the PROPER DSS.

The spreadsheet based matrix is supported by an accompanying User Guide (P3.4) and Technical Manual (P3.5) which together explain the methodology in more detail and describe the scientific and technical approaches adopted. Reference to these documents allows the more experienced user to:

- modify allocated grades depending on local circumstances
- develop grades for 'alternative treatment types' should the user wish to evaluate the use of further/proprietary treatment technologies within the DSS

The PROPER decision support system has been tested on five case studies involving rural highway drainage catchments in the UK and Ireland (P3.6). The case study sites represent different combinations of site criteria and performance matrix conditions (percentage weightings of criteria/indicators) to illustrate the impact of these variables on predicting both the suitability and order of preference for the 12 different SuDS/BMPs. Each of the case study sites drains to established treatment systems enabling comparisons to be made between the installed system and the predicted suitability and preferential order of treatment potential for different SuDS/BMPs at the drainage site. The treatment effiiciencies of the diifferent systems, together with the factors which influence them, have been described in P3.1 and P3.2.

Not suitable
Suitable with advisement
Suitable

Input
your indicator weighting;
the total should be equal to 100

Input your indicator grade [1-5]
non-applicability under the environmental criterion is in

Criteria	Criteria weightings	Indicators	Indicator weightings		Swale (SW)	Filter strip (FS)	Filter drain (FD)	Soakaway (SO)	Infiltration trench (IT)	Infiltration basin (IB)	Retenti
Technical	40	Flood control	20		2	2	3	3	3	4	
		Pollution control	15		2	1	3	4	4	5	
		Adaptability to highway widening and climate change	5		2	1	2	3	2	2	
Environmental	20	Impact on receiving water volume	8	Surface water	2	2	3	0	0	4	
				Ground water	2	2	3	4	4	5	
		Impact on receiving water quality	8	Surface water	3	3	4	0	0	5	
				Ground water	2	2	3	3	3	4	
		Impact on receiving water ecology	4	Surface water	2	2	1	0	0	3	
				Ground water	3	3	3	3	3	3	
Operation and maintenance	10	Maintenance and servicing requirements	10		3	4	5	4	5	5	
Socio-environmental awarene	5	Sustainable development (biodiversity)	3		4	3	2	1	2	2	
		Aesthetics and public awareness	2		4	3	2	1	1	4	
Economic	10	Unit rate costing	10		4	5	1	2	2	4	
Legal and highway planning	15	Compliance with the EU Water Framework Directive objectives	15		3	5	4	4	4	1	
Total weighting	100		100	Sum of weightings x grades	260	287	305	328	336	368	

(a)

Input here the SUDS/BMP percentage contribution to surface and groundwater

		Swale	Filter strip	Filter drain	Soakaway	Infiltration trench	Infiltration basin	Retention pond	Detention basin	Extended detention basin	Constructed wetland	Porous surfacing (without storage)
Contribution to	Surface water	25	75	50	0	0	25	100	100	100	100	50
	Groundwater	75	25	50	100	100	75	0	0	0	0	50

(b)

Figure 2.8. Screen shots of the 'Performance matrix' page of the PROPER DSS tool showing (a) part of the performance matrix and (b) part of the table for allocating the percentage contributions made by different SuDS/BMPs to surface waters and groundwater

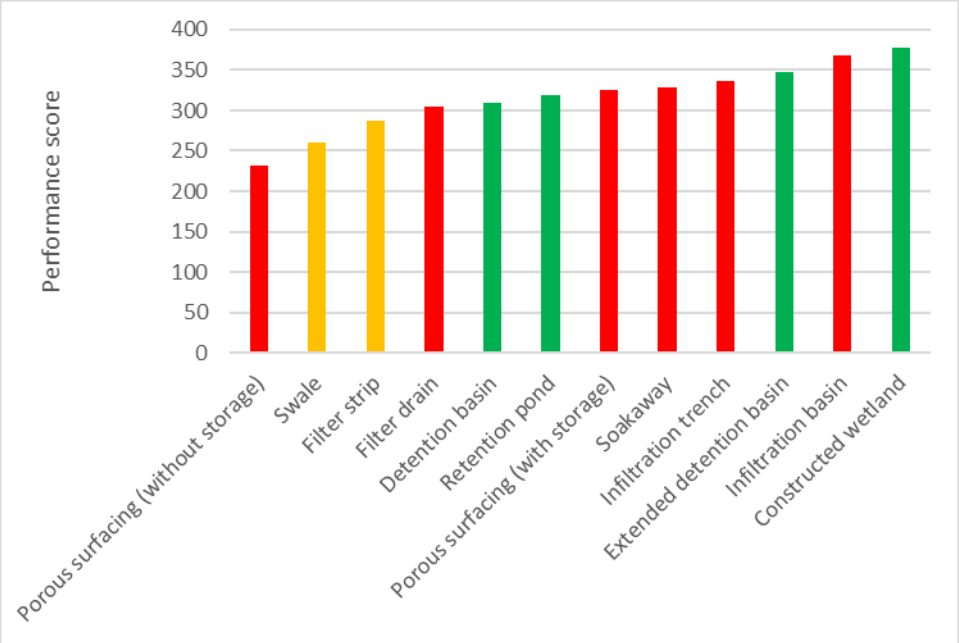

Figure 2.9. Summed performance scores identifying the suitability of different treatment systems at the Luton M1 site

2.6.3. Treatment of microplastics (MPs) and organic micropollutants (OMPs)

2.6.3.1. Processes influencing removal in treatment systems

The removal of organic micropollutants (OMPs) and microplastics (MP) from highway runoff by sustainable drainage systems is a function of both the susceptibility of pollutants to various treatment processes (see MICROPROOF Deliverable 4.1 (M4.1)) and the treatment system design, which defines the potential for treatment processes to occur. The processes contributing to removal are informed by their bio-physico-chemical characteristics such as sorption to particulate matter or precipitation followed by sedimentation or filtration. Although MPs come in a variety of types and densities (some of which are less dense than water) the adhesion of buoyant MP particles into a 'snow' with a resultant density that promotes settlement has been reported (Liu et al., 2019). OMPs can be susceptible to aerobic and anaerobic biodegradation and photolysis with efficiencies being dependent on both the structure of the OMP and treatment system design. However, there is the potential for the resulting breakdown products to present environmental problems with an example being the formation of aminomethylphosphonic acid (AMPA) during glyphosate degradation (Imfeld et al., 2013).

2.6.3.2. Experimental results and modelling for removal in treatment systems

Because the processes that are involved in retaining OMPs and MPs in highway runoff treatment systems are only understood at a generic theoretical level (Scott and Frost, 2017; Guan et al, 2018), the removal of OMPs/MPs by sustainable treatment technologies needs to be supported by experimental field studies directed at specific substances. The data available for highway runoff treatment systems is summarised in MICROPROOF Deliverable 4.2 (M4.2). Polyaromatic hydrocarbons (PAHs) are the most widely studied OMP with both storage treatment systems (e.g. retention ponds and wetlands) and filtration and infiltration systems demonstrating positive removal efficiencies for several PAHs. However, with only a limited number of OMP treatment studies available and challenges in comparing data sets (i.e. differences in sample collection, inlet concentrations, system age, design and operation and maintenance regime), it is currently not possible to confidently identify removal efficiencies for OMPs within different treatment types. Only a single study on the performance of stormwater ponds to retain MPs has been reported (Olesen

et al. 2019) but this excluded tyre wear particles. However, based on a MP retention of approximately 85%, which is similar to that reported for particulate matter in stormwater ponds, it was predicted that tyre wear particles would be retained to a similar degree.

In an attempt to address the lack of experimental data, process-based models (see M4.2) to predict the treatment performance of OMPs/MPs in highway runoff treatment systems have been proposed (e.g. Vezzaro et al., 2014; Vollertsen et al., 2012). However, these models are typically site specific or have yet to be validated in the field. In addition, while attempts to model treatment performances are appropriate for well characterised pollutants (such as metals), their reliability is inhibited by a lack of the required information on the environmental behaviour and fate of OMPs/MPs. Given the limited field data and lack of availability of validated models, M4.2 provides a simple qualitative overview of the fate of OMPs within four types of sustainable treatment systems, which is based on an evaluation of whether the OMP is particulate, has a high affinity to sorb to solids or a low affinity for solid sorption. If a substance readily degrades and sorbs easily to solids, it has a high probability of being retained/removed in all types of treatment systems. If it is slowly degradable and sorbs poorly to solids, it is unlikely to be removed, particularly in treatment systems with a short hydraulic residence time. It is envisaged that microplastics represented by tyre wear particles will behave similarly to other organic particles of a similar size, and therefore be susceptible to the same levels of removal. The results of applying this approach are shown in Table 2.13 with green shading indicating good retention/removal, yellow indicating moderate retention/removal and red indicating poor retention/removal. In very general terms it can be seen that systems based on slow soil filtration tend to achieve the higher removal rates. However, this is only true as a general trend, and the actual efficiencies will be dependent on treatment system design and layout. Therefore, to overcome the limitations of the current qualitative approach further investigations will be necessary based on specific OMPs and MPs.

Table 2.13 A qualitative assessment of the fate of OMPs in four types of stormwater management facility

Type of stormwater management facility	Characteristics of a specific OMP			
		Particulate	Sorbs well to solids	Sorbs poorly to solids
Employs a wet retention volume	Easily degradable			
	Slowly degradable or inert			
Employs slow soil filtration	Easily degradable			
	Slowly degradable or inert			
Employs rapid soil filtration	Easily degradable			
	Slowly degradable or inert			
Employs rapid soil filtration or ballasted sedimentation	Easily degradable			
	Slowly degradable or inert			

2.6.3.3. Development of a Decision Support Scheme based on risk assessment and treatment efficiencies.

To support highway practitioners in identifying the need for and type of OMP/MP treatment required on a site-by-site basis, the results of the environmental risk assessment for 11 organic micropollutants (see MICROPROOF Deliverable 3.1 (M3.1)) have been integrated with the qualitative information on treatment efficiency to develop a decision support system (DSS) (see MICROPROOF Deliverables 4.3 and 4.4 (M4.3, M4.4)). A flow chart showing the progressive stages in the application of the DSS is shown in Figure 2.10 and the results of its application are shown in Table 2.14. Table 2.14 is also available as an Excel chart (M4.3)

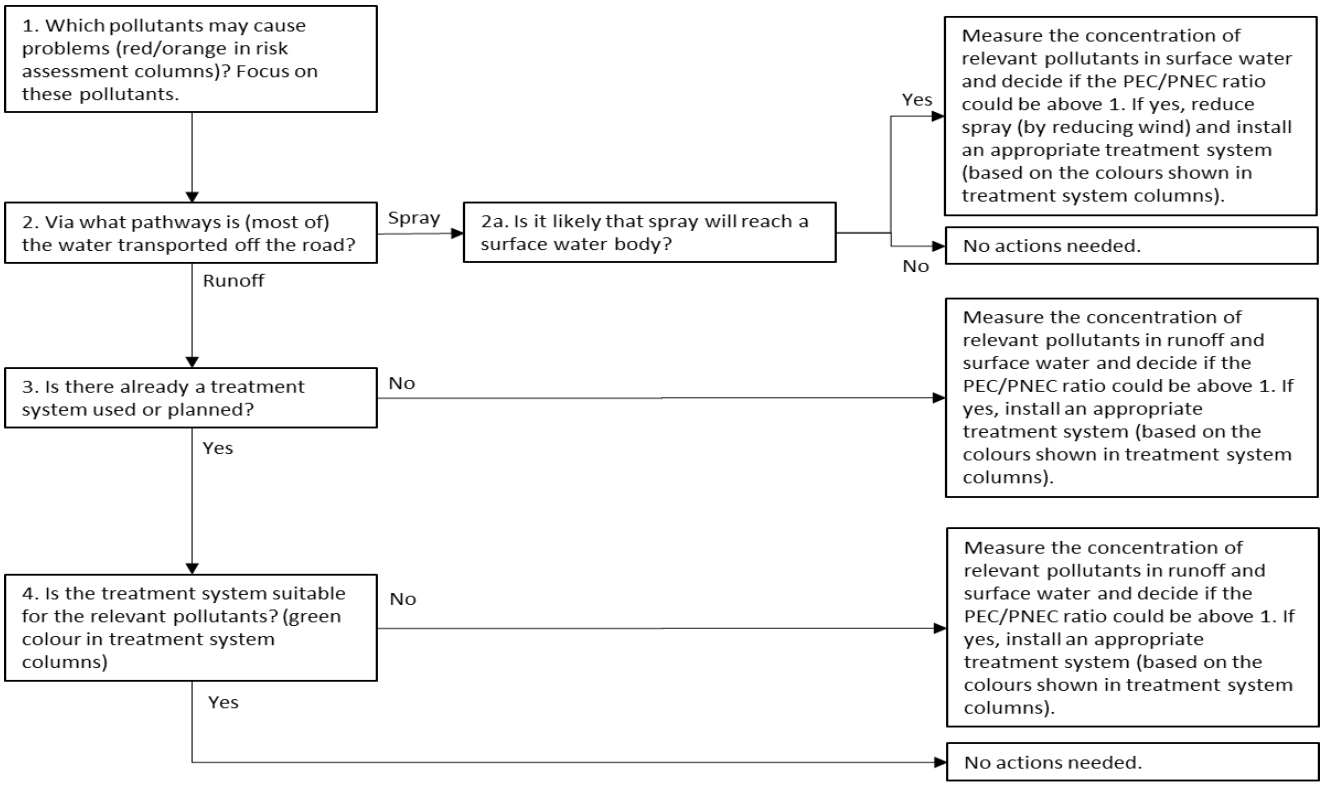

Figure 2.10. Flowchart to support use of the MICROPROOF decision support scheme combining risk assessment and treatment efficiencies for OMPs/MPs

Following confirmation that a specific OMP/MP is a pollutant of concern (Box 1; Figure 2.10), the pollutant transport pathway (i.e. via spray or runoff) from the highway to the receiving surface water is established (Box 2; Figure 2.10). Where a runoff route is confirmed and there is no treatment system in place, further chemical analysis is recommended to enable a site-specific risk characterisation assessment to be completed. If a risk characterisation ratio >1 is calculated then the installation of an appropriate treatment system can be recommended or where an existing treatment system is considered inadequate appropriate changes or replacement can be suggested. Consultation of Table 2.14 allows an appropriate type of sustainable drainage system (SuDS) to be identified for each of 11 selected OMPs/MPs. For the majority of these pollutants all the considered treatment systems are shown to be efficient. This is not the case for hexa(methoxymethyl)melamine although currently it is not considered to pose a risk in the water environment. In contrast, tolyltriazole poses a high risk when attached to suspended solids but removal by treatment systems is, at best, only of moderate efficiency (using either a wet retention or slow soil filtration).

Table 2:14. MICROPROOF decision support scheme which combines the results of the risk assessment with the results of the treatment systems review

Pollutant		Pollutant characteristics			Risk Assessment													Types of treatment systems			
					Runoff						Surface water										
					Water				Suspended solids		Water				Suspended solids						
					DE A61		SE E18		DE A61	SE E18	NL A2		Estimate		NL A2	NL Rhine	Esti-mate				
Pollutant	CAS number	Degradable	log Kow	XLogP3	PEC/ PNEC	PAF	PEC/ PNEC	PAF	PEC/ PNEC	PEC/ PNEC	PEC/ PNEC	PAF	PEC/ PNEC	PAF	PEC/ PNEC	PEC/ PNEC	PEC/ PNEC	Wet retention volume	Slow soil filtration	Rapid soil filtration	Technical rapid filtration or ballasted sedimen-tation
Rubber (tyre wear)		Slow			*177273*	*86%*	*2955*	*61%*	*1500000*	*130000*	*18*	*22%*	*364*	*44%*	*3000*	*3000*	*12000*	+	+	+	+
Benzo(a)pyrene	50-32-8	Slow	6,13	6	6,9	0,5%	4,8	0,4%	0,5	0,1	0,6	0,1%	48,8	2,1%	0,0	0,1	0,0	+	+	+	+
Fluoranthene	206-44-0	Slow	5,2	5,2	0,5	0,1%	0,5	0,2%	1,2	0,2	0,2	0,1%	57,9	1,3%	0,1	0,2	0,2	+	+	+	+
Nonylphenol	104-40-5	Moderate	4.48 - 5.4	5,9	0,0	0,2%	<	0,2%	0,0	<	<	0,2%	0,0	0,0%	0,0	0,0	0,0	+	+	+	+
4-tert-octylphenol	140-66-9	Easily	4,12	5	2,0	0,2%	0,2	0,0%	907,5	329,1	<	<	0,0	0,0%	<	2,6	3,7	+	+	+	+
Di(2-ethylhexyl)phthalate	117-81-7	Moderate	4.8 - 9.6	7,4	0,5	3,6%	0,6	3,8%	0,7	0,0	0,8	4,9%	0,0	0,1%	0,1	0,1	0,0	+	+	+	+
Bisphenol A	80-05-7	Easy	3,4	3,3	0,0	0,1%	0,1	0,3%	3,9	0,9	<	0,0%	0,0	0,0%	<	0,1	0,9	+	+	+	+
Mercapto benzothiazole	149-30-4	Slow	2,86	2,4	0,0	<	<	<	6,9	1,3	<	<	0,0	0,0%	0,0	<	0,1	+/-	+/-	-	-
Tolyltriazole	29385-43-1	Slow	1,081	1,4	0,0	NA	0,0	NA	366,2	13,1	<	NA	0,0	NA	1,9	2,1	76,7	+/-	+/-	-	-
Diisodecyl phthalate	26761-40-0	Moderate	8,8	10,6	4,3	NA	1,0	NA	42,3	1,4	<	NA	0,1	NA	0,6	0,2	0,3	+	+	+	+
Hexa(methoxymethyl)melamine	3089-11-0	Moderate	1,61	1	0,1	NA	0,0	NA	0,2	0,0	0,0	NA	0,0	NA	<	<	0,7	-	-	-	-

Key: XLogP3 ; Source: https://pubchem.ncbi.nlm.nih.gov/;
log Kow; Source: see M3.1
Red colour in the risk assessment columns = pollutant may cause a risk for aquatic environment.
Red colour in the treatment systems columns = the treatment system may not be appropriate for treating a certain pollutant.
Please note that the results of the risk assessment for tyre wear is uncertain (see M3.1).

2.6.4. Management of de-icing salts

2.6.4.1. Alternatives to sodium chloride de-icing salts

Based on a review of the peer-reviewed and grey literature (primarily that held by the National Road Authorities; NRAs), a range of de-icing agents are identified and categorised into one of three groups (see Table 2.15).

Table 2.15. Classification of de-icing agents

Group 1: Chloride based

- Sodium chloride
- Magnesium chloride
- Potassium chloride

Group 2: Organic based

- Potassium formate
- Sodium formate
- Calcium magnesium acetate
- Sodium magnesium acetate
- Potassium acetate
- Sodium acetate
- Monopropylene glycol
- Fructose/glucose sodium chloride
- Beet juice

Group 3: Other

- Urea
- Geothermal heating

The most commonly used alternatives to chloride based salts are acetates (e.g. potassium, sodium and calcium magnesium) and formates (e.g. sodium and potassium). Identified benefits include their non-corrosive nature leading to reduced wear and tear on vehicles and road infrastructure. Further alternatives include the use of fermentation by-products such as beet-juice and fructose-based solutions, often mixed with a low concentration of sodium chloride (~12% by mass). Although having reduced chloride, these alternative de-icers also have an environmental impact. All organic alternatives exert a significant biochemical demand on receiving waters, reducing dissolved oxygen levels and impacting negatively on receiving water ecologies. Further formate- and acetate- containing salts contain cations which alter soil structure and can cause leaching of previously bound metals. Whilst elevated BOD levels can be mitigated through the use of point control treatment options, these are generally costly to construct and operate. In terms of full-scale field trials, only a limited number of studies have been identified with results reported varying from no negative effects on receiving environments (calcium magnesium acetate) (LaPerriere and Rea 1998) to an unpleasant smell and stickiness (beet juice/sodium chloride mix). An exception to the limited use of alternative de-icers is the increasing use of potassium formate in Finland over the last 15 years following a commitment to use only biodegradable de-icing agents in catchments which drain to aquifers critical to drinking water supply. However, whilst its use is increasing, no data on its environmental impacts are reported.

2.6.4.2. Cost benefit analysis

Only a limited amount of information could be sourced from either the peer-review or grey literature and therefore only a general discussion is available. Insufficient data exists to support an analysis of the costs of de-icing agents in Europe and therefore Table 2.16 presents the relative costs of de-icing agents in the USA.

Table 2.16. Comparative costs of de-icers based on US data reported by Kelting and Laxson (2010)

De-icing chemical	Cost in $/metric ton
Sodium chloride	37
Calcium chloride	125
Magnesium chloride	99
Calcium magnesium acetate	1328
Potassium acetate	1038

Although the data indicate that alternatives to sodium chloride are considerably more expensive (per metric ton), research which balances this against estimated costs of, for example, sodium chloride damage to road infrastructure, vehicle corrosion and degradation of sensitive areas has reported net saving involving the use of calcium magnesium acetate (Vitalino, 1992). Given that the majority of the information on alternatives to de-icing salts is held by the NRAs, the following recommendations are made:

- CEDR should translate national/local language NRA studies on alternative de-icers into a common language to facilitate their interrogation and dissemination
- A common reporting structure should be developed to enable cost comparisons between de-icing studies to be undertaken.

2.6.5 Treatment during construction activities

2.6.5.1 Treatment of runoff from road construction sites

Suspended solids are identified as the key pollutant of concern within highway construction surface runoff, both directly (as a pollutant in its own right) and indirectly (as a carrier of different pollutant types), which can lead to a range of on-site and off-site impacts (P4.1). The management of surface runoff within highway construction sites includes both space- and time-limitations. For example, the construction of highways often involves the manipulation of extended corridors of land which typically pass through a number of different environments/geologies/catchments including the need to cross water bodies and to excavate in depth, potentially affecting aquifers and this presents considerable problems for member states such as Ireland and Slovenia possessing substantial karstic bedrock and sensitive aquifers. Managing surface runoff generated during highway construction can hence be extremely challenging, with the clearing of land exposing soils which are readily mobilised by rainfall (see Table 2.17. Whilst the time period for construction may represent only a fraction of the total life span of a highway and its catchment footprint may be relatively low, the impact of runoff derived during this phase can be disproportionally large, with the range of reported impacts varying from fish kills to reduced macroinvertebrate counts.

Treating runoff from highway construction sites can be challenging, as large runoff volumes are generated with limited space available to divert flows and/or install treatment systems. Hence the use of onsite erosion control measures should be prioritised through, for example, use of the following generic principles (SEPA, 2009):

- divert (clean water away from sites),
- minimise erosion (from exposed soils)
- prevent (contaminated runoff from entering water courses)

Commonly used temporary on-site control approaches for reducing sediment loads mobilised by highway construction runoff include utilisation of existing vegetation, establishment of new

vegetation, diversion drains, bunds, check dams, silt fences and sustainable drainage systems (SuDS). However, if following their use, further treatment is required, there are several possible treatment approaches for removing sediments (and associated pollutants) from highway construction site runoff. The US Federal Highways Administration (FHA) identifies the following principles when considering treatment measures for reducing loads of suspended solids in surface runoff (Johnson, 2003) as follows:

- Reduce water velocity e.g. front-end sedimentation ponds/gross pollutant traps etc.
- Divide runoff into smaller volumes e.g. use of multiple cellular systems
- Promote infiltration
- Provide mechanical or structural retention methods

Table 2.17. Overview of studies reporting data on the levels of sediments mobilised by highway construction runoff

Parameter	Concentration	Authors	Country
Suspended solids	1390 mg/l (returned to pre-construction levels of <5mg/l after construction)	Barton (1977)	In stream (Canada)
	60 and 130 mg/L (from a preconstruction maximum of 30mg/l)	Embler and Fletcher (1983)	In stream (USA)
Sediment yield	Increased by 2 orders of magnitude	Hainly (1980).	USA
	x20 times the sediment during the 2 month highway construction phase than during the previous 12-months	Duck 1985	UK
Suspended solids	x450 the background level of TSS recorded	SEPA (2009)	UK
	Maximum concentration: 91-1442 mg/l	Kalainesan et al., 2009	Data from 4 sites, USA
Total solids	Six-fold increase in total solids leaving the site during construction.	Cleveland and Fashokun (2006)	USA
Total suspended solids	Higher concentrations reported D/S of highway construction site in comparison to U/S	Chen et al., (2009)	USA
Suspended solids	No significant difference between U/S and D/S sites during highway construction (except when control measures failed).	Huang, and Ehrlich, (2003)	USA
	Catchment 1: 326-20,340 mg/l	McNeill (1996)	UK
	Catchment 2: 103 – 46,800 mg/l		
	Catchment 1: U/S of construction: 2-8 mg/l; D/S of construction: 35–1854 mg/l		
	Catchment 2: U/S of construction: 4-11 mg/l D/S of construction: 350 – 3660 mg/l		

Key: U/S = upstream; D/S = downstream

The optimal type of treatment system will depend on local conditions e.g. volume of water generated, types of pollutants (particularly suspended solids load) and the amount of space available to install a system (SEPA, 2009). Depending on the site circumstances, one or more systems may be required in combination.

In terms of performance data, only a limited number of studies are available. For example, Kayhanian et al. (2001) reports the results of a study monitoring the quality of runoff from 15 highway construction sites. A range of types of highway construction sites (e.g. new constructions, highway widening schemes etc.) were included in the 15 sites and samples were collected downstream of any treatment systems which included, for example, silt fences, vegetated berms and straw bales. Whilst the types of SuDS are identified per site, the results are presented as a single data set and therefore it is not possible to draw any conclusions regarding the level of treatment offered by a particular SuDS. However, the study concluded that, following SuDS treatment, concentrations of a range of pollutants in highway construction site runoff were less

than those typically identified for operational highway runoff. The exceptions to this conclusion were chromium, nickel, phosphorus and TSS. While the source of the elevated metals was not clear, mean concentrations of TSS in highway construction runoff (499 mg L^{-1}) were associated with exposed grounds and exceeded mean concentrations reported for operational highway runoff by a factor of 3 (160 mg L^{-1}). Similarly, a study of the performance of a range of highway construction runoff treatment devices (identified to include detention basins, gross pollutant traps and sand filters) was reported to reduce transported metal loads by 80%, but removal efficiency per system type was not reported (Ball et al., 2000). In their impact assessment of highway drainage on surface water quality, Bruen et al. (2006) recommend the early installation filter drains on highway construction sites to treat surface runoff prior to discharge, but do not report any specific highway construction runoff performance data. The same study reports the common use of retention ponds, silt traps and open drains during highway construction projects in Ireland to prevent the pollution of receiving waters but, again, no specific performance data is reported (Bruen et al., 2006). However, in Ireland, runoff from road construction sites is considered to represent a significant issue in the EIA of road projects, particularly where sensitive ecosystems are likely to be impacted.

2.6.5.2. Guidelines on the treatment of runoff from construction sites

The review of the construction road runoff literature (P4.1) has indicated a high level of awareness of the need for measures to manage highway construction runoff. The EU Environmental Impacts Assessment (EIA) Directive (1985; 2011; 2014) identifies the construction of motorways as requiring an EIA as part of the planning application process. However, at a national level, although most European countries have guidelines which identify good surface runoff management practice at a generic construction project level only these do not extend specifically to road construction sites. In Slovenia a case study has provided a good example of how generic approaches to managing construction site runoff can be applied to a highway construction project (P4.2). In Scotland, SEPA (2009) promote the use of the following systematic approach to minimising construction erosion and controlling sediments:

- Identification of the location of all surface waters, groundwater and drainage path
- Identification of protected habitats and species.
- Assess potential flood risks and sources of pollution
- Consider timing of works in relation to weather and other sector needs
- Make space for treatment system
- Train staff in routine and accidental pollution prevention
- Develop emergency procedures.

The Swiss Society of Engineers and Architects (SIA) has provided recommendations (SIA 431) which describe the work and measures which are advised in the planning and operation of drainage from construction sites (SIA, 1997). The overall objective is to ensure that the drainage from construction sites and any subsequent handling, storage and transfer does not have any negative impact on the soil, surface waters, groundwaters or wastewater treatment plants. Specific treatment processes which are identified include neutralisation, flocculation and sedimentation with guidance given on the dimensioning of sedimentation ponds. Further Swiss guidelines dealing with highway drainage are provided in Appendix 2 together with national guidelines from Germany, Sweden, Norway and Austria for road drainage during both the construction phase and during normal operating conditions.

3. Conclusions

3.1. How the three projects have addressed the Description of Research Needs (DoRN) and the recommendations of State-of-the-Art report 2016 (SoAR)

The SoAR (Meland, 2016) and the DoRN recommend that NRA's should work collaboratively with environmental agencies and water authorities at a national and/or European level to meet legislative requirements for receiving waters. For example, NRAs should seek to be proactively engaged in the co-development of river basin management plans as part of meeting the EU WFD (2000) requirements. To support NRAs in undertaking these activities, the (SoAR) proposed the following ways to take this recommendation forward. These recommendations are identified below together with an evaluation of how the work undertaken within PROPER, LUNT and MICROPROOF has contributed to implementing these actions:

R1: NRAs should work with environmental agencies at national or European level to initiate and develop a common understanding of when and how road runoff should be treated:

Each of the three projects (PROPER, LUNT and MICROPROOF) has worked with a range of stakeholders (including water authorities and environmental agencies) to foster new relationships and develop a common understanding of the opportunities and challenges around managing highway runoff and the quality of surface water and groundwater. In addition, the Program Executive Board (PEB) has considered these issues from the early phases of the project and involved important stakeholders over the entire period of the project. Experts from water and environmental protection authorities, and researchers have been invited to project meetings and continuously encouraged to be involved in the progress of the project.

The project teams have also consistently supported stakeholder involvement. For example, the PROPER project established an International Advisory Board which included representatives from the Portuguese and Scottish environmental agencies, the Swedish Agency for Marine and Water Management, NRAs, policy and infrastructure development companies. This provided an opportunity to align outputs with current practice and to disseminate them widely. Likewise LUNT and MICRPROOF undertook a series of interviews with health, safety and environment (HSE) and procurement departments of European NRAs to inform an analysis of current practice including types and quantities of de-icing salts as well as salting technologies (L1.1 and 1.2).

These connections and initiatives will contribute to providing a solid platform for further cooperation between NRAs and stakeholders, mainly water and environmental authorities. In turn, this will pave the way for NRAs to further develop practical nature-based strategies to reduce the negative impact of highway construction and the use and operation of highways on the environment.

R2: Exchange of knowledge and experience concerning existing guidelines:

Each of the three projects, together with the PEB, has contributed to reviewing a range of available guidelines (at NRA and national levels) pertaining to the management of runoff water from roads (construction phase and road operation) from the perspectives of a range of conventional runoff pollutants (PROPER), de-icing chemicals (LUNT) and MPs/OMPs (MICROPROOF). At national levels there are guidelines that focus on mitigating road runoff and consider the quality of surrounding water bodies during road construction and operation. An overview of these guidelines is given in Appendix 2.

Together the three projects have extended existing knowledge regarding the relationships between pollutant removal processes and their relative ability to occur within alternative treatment types. This contributes to supporting the selection of sustainable treatment systems from a pollutant removal perspective and complements the use of field data, when selecting appropriate treatment systems. The importance of maximising the opportunities for multi-functional beneficial processes to occur in treatment systems is emphasised (e.g. P3.1 and M5.6).

R3: Further applied and praxis-oriented research:

NRAs should continue to support, initiate and conduct research that will help improve water management in terms of meeting the requirements of the WFD and other relevant regulations/directives. Involvement in the current CEDR research call 2016 (Part Water Quality), has focussed on the synthesis and sharing of existing knowledge, and participating in PROPER, LUNT and MICROPROOF activities (e.g. reviewing project deliverables and attending PEB meetings). Between them, the three projects have produced 36 outputs including reviews of the literature and the development of new decision support tools (see Appendix 1). This report contains a synthesis of key findings and recommendations for the NRAs for both implementation into practice and further research. However, implementation could be a challenging task, considering the different structural, organisational, language, geographical, climatological and geological aspects.

R4: The NRAs and CEDR should continue the work started in SP3 and SP4, as water management will remain an important issue at both national and European level:

The third strategic plan (SP3) covered the time period 2013-2017 with the establishment of TG15, the Meland (2016) report and the subsequent 2016 research call. These pave the way for NRAs to develop strategies to reduce the negative impact of highway construction and operation on the environment. Commencing in 2017, the three projects have been implemented within SP4.

Table 3.1 provides an overview of the research needs according to the (DoRN) document, which was prepared based on experience and knowledge exchange among the participating National Road Authorities (NRAs) In addition, the deliverables from the three projects, which include the identified needs within their scope, are referenced. The extent to which project deliverables fully identify research needs varies as a function of publicly available data and information sets.

Table 3.1. Overview of research topics identified in the SOAR, and included in the DoRN 2016 and deliverables which have considered them.

Research topic	Subtopic	Included in DoRN 2016	Deliverables addressing the identified research topics/sub-topics
Risk assessment tools for deciding when road runoff should be treated	Establish models that predict the pollution concentrations and loadings in road runoff	Yes	P1.2
	Establish methods for assessing the water bodies' vulnerability to polluted runoff	Yes	P2.2; P2.5; L2.1; L2.2
The performance and cost-benefit of treatment systems for polluted runoff including tunnel wash water	Increase knowledge of the treatment performance and cost-benefit of existing treatment systems (e.g. SUDS/BMPs) and technically advanced treatment	Partial (only SuDS/BMPs in scope)	P3.1; P4.1; L3.1; L3.2
	The treatment performance and cost-benefit of commercially available technical filter materials compared with soil filters	No	
	Long-term soil filter performances. Efficiency vs investment and operational costs	Partial	P3.1
	Alternative treatments for tunnel wash water	No	
	Treatment methods that reduce the impact of high levels of chlorides	Partial	L3.1; L3.2
Performance and cost-benefit of runoff treatment systems during road construction including tunnelling water	Denitrification of water from construction sites contaminated with undetonated explosives	No	
	Treatment methods for runoff water during construction	Yes	P4.1; P4.2
	Recycled material e.g. concrete and asphalt in the construction of new roads which may leach hazardous substances into the aquatic environment.	No	
Environmental impacts of de-icing chemicals	Chemical impacts and stratification in lakes and streams due to the use of road salt (NaCl)	Yes	L2.1; L2.2
	Chemical impacts on ground- and surface water bodies due to the use of alternative de-icers	Yes	L3.1; L3.2
	Cost-benefit analyses: comparisons of road salt and alternative de-icing chemicals and other physical and mechanical measures	Yes	L3.1; L3.2
New and emerging chemicals	New technology and materials in the car industry which may change the content and composition of pollutants in road runoff.	Not specific objective	All reports increase awareness
	New technology and materials in the construction industry which may change the content and composition of pollutants in road runoff.	Not specific objective	All reports increase awareness
	The screening of new and emerging chemicals in road runoff	Yes	M1.1, M2.1
	Microplastics in the environment is a hot topic with tyres believed to be a significant source of plastic in the environment; are there other sources from roads and traffic?	Yes	M1.1, M1.3
Climate change and water quality	Climate change, with increased and intense precipitation will affect road runoff in terms of road runoff volumes (flooding) and pollution loadings/concentrations.	Not specific objective	
Meta Studies	Transnational coordination of existing research results	Yes	P1.1; P2.1; P3.1; P4.1; L1.1; L1.2

3.2. Communication between PEB, project teams and stakeholders

As shown in Figure 3.1, a multichannel communication scheme has been adopted over the duration of the project. The PEB communicated with the three project teams through a designated project contact person.

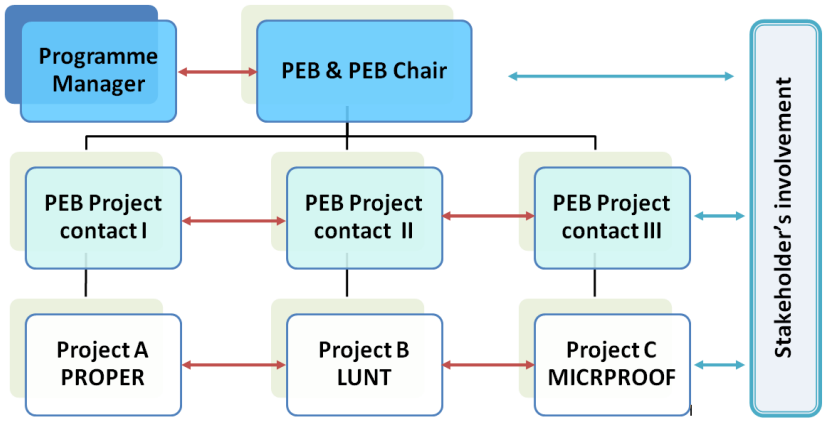

Figure 3.1: Communication scheme between PEB and the project's teams

To support the dissemination of outputs to a range of stakeholders including NRAs, environmental agencies and researchers, the PEB and the three projects held two meetings each year including a mid-term evaluation workshop held in Germany in October 2018 and a final workshop in Portugal in October 2019, where several stakeholders were involved.

The final workshop was organised by the PEB and hosted by the National Laboratory for Civil Engineering (LNEC) in Lisbon, Portugal on the 8th and 9th October 2019. The workshop programme provided the opportunity for the three projects to present key results, and offered an opportunity for a range of practitioners from highway construction, operation and management/regulation to present on key research activities/issues from their perspectives. The topics covered together with the presenters and their affiliations are identified below:

- Introduction to the CEDR Call 2016 Transnational Research Programme Water Quality - A Strong Foundation for a Sustainable Future.
  Birgit Kocher (Federal Highway Research Institute - Germany)
- European road network and related environmental aspects
  Birgit Kocher (Federal Highway Research Institute - Germany)
- PROPER project: Risk assessment and risk management.
  Jes Vollertsen (Civil Engineering - Aalborg University - Denmark)
- LUNT project: Environmental impacts of de-icing chemicals
  Tone Muthanna (Norwegian University of Science and Technology - Norway)
- MICROPROOF project: New and emerging chemicals- including micro-plastic
  Rianne Dröge and Peter Coenen (TNO - Netherlands)
- A new road: Road runoff and water quality aspects
  Frode Kroglund (County Governor of Agder, Norway)
- Road runoff treatment during construction phase - Slovenia as a case study
  Mihael Brenčič (University of Ljubljana - Slovenia)
- The Finnish Transport Infrastructure Agency's guidelines for ground water protection along roads.
  Marja-Terttu Sikiö (The Finnish Infrastructure and Construction Service, Finland)

- Sedimentation versus filtration: background and tendencies with Lake Constance as an example
  Michael Konnerth (District Office Lake Constance Region - Germany)
- Treatment of road runoff in Switzerland: State of the art
  Michele Steiner (Consultant – Road Runoff Treatment - Switzerland)
- The test site E18 in Sweden: Actual results
  Göran Blomqvist (Swedish National Road and Transport Research Institute - Sweden)
- Organic pollutants in road runoff: sources, pathways and treatment strategies
  Stephan Fuchs (Karlsruhe Institute of Technology - Germany)
- Tyre wear and microplastic in road runoff and the surrounding environment
  Daniel Venghaus (Technical University Berlin - Germany)
- From confrontation to co-operation - tackling road pollution collaboratively
  Phil Chatfield (Former Policy Advisor at Welsh Government - UK)

Presentations are available on the CEDR website www.cedr.eu and on the PROPER website: http://proper-cedr.eu/

3.3. Conclusions and recommendations

The NRAs (represented by the PEB members) have identified an implementation strategy as an important requirement from this project. This strategy should act as a baseline for complementary measures to bridge the gap between research and the implementation of research results from the CEDR Transnational Research Programme Call 2016, part Water Quality. Successful implementation requires other key complementary elements such as early engagement with relevant stakeholders and cooperation with other relevant road transport areas, programmes and initiatives.

Based on the findings of the PROPER, LUNT and MICROPROOF projects, Table 3.2 identifies a series of possible measures that, if implemented by NRAs, would support a systematic shift towards the European road network reducing its environmental impact on receiving waters. All identified measures are considered to be of pan-European interest, and reflect evaluated evidence-based outcomes. Each measure is supported by a brief consideration of the benefits to NRAs of developing a strategy to implement them. The principal recommendations concern future continued implementation of source infiltration-based treatment systems, enhanced modelling capabilities and improved salting operations/ technologies.

The measures identified in Table 3.2 represent areas which are considered sufficiently mature for NRAs to implement within their current remit. However, the project teams and the PEB have identified a number of areas for further investigation where gaps in knowledge could prevent NRAs from taking further steps towards adopting sustainable highway drainage solutions as a basis to minimise receiving waterbody impacts (see Table 3.3). Each knowledge gap is associated with a brief discussion of the benefits that might be gained by carrying out further research in the respective areas.

Further research needs to improve working knowledge and enhanced implementation of appropriate and effective treatment systems are identified as priority areas. It is considered that further investigation of the identified research needs would lead to a considerable improvement in performance effectiveness of SuDS/BMP controls receiving highway runoff and so make a significant contribution to enhancing the sustainability of the European road transport network.

Table 3.2. Recommended measures for Implementation.

Measures	Beneficial outcomes
Development of a harmonised approach to facilitate collection of compatible and comparable site source data across Europe.	Facilitation of 'good quality' site data to provide a basis for more robust data comparisons and to support more consistent generic modelling approaches. The enhancement of site source monitoring databases particularly in relation to the incorporation of contaminants of emerging concern such as microplastics.
Routine Inclusion of physico-biochemical pollutant characteristics within studies of receiving waterbodies impacted by road runoff.	Supporting more accurate interpretation of likely pollutant behaviour during mobilisation, treatment and discharge; enabling more robust risk assessment methodologies and helping the understanding of the potential interaction of highway discharges with receiving waterbody biota; assisting the integration of ecological population/community techniques with analytical chemical determinations
Improved predictive equations for groundwater pollutant impacts and mass flow analyses especially in relation to unsaturated zone flow analysis	Provision of an improved understanding of pollutant dispersion and dynamics especially for metal, organic and salt species; enhanced knowledge of pollutant mobilisation in roadside soil systems subject to road runoff infiltration
Ensure consistency of data between OMP and MP source emission factors and road runoff concentrations for specific substances	Establishing a more accurate and robust basis for prediction of OMP/MP road runoff loadings
Introduction of regular and systematic pan-European NRA collaboration on salting application	Development of harmonised European NRA salting questionnaires and operating methodologies as well as national cost comparisons; improved national awareness and knowledge transfer of salting operations and technologies; encouragement of the translation of national/local language NRA road salting reports/studies to facilitate interrogation and dissemination.
Roadside infiltration systems as first-choice highway drainage systems	The project gave some recommendations on «new» pollutants to include in surveys; on the current status and common European platform on the topic microplastics; and a comprehensive overview over different treatment solutions. Achievement of sustainable 'on or near highway' source drainage to minimise receiving waterbodieswaterbody risk and impact is also recommended.
Collection of data on SUDS/BMP treatment systems should consider generic pollutant properties and unit operating processes as a basis to evaluate their performance effectiveness	Improved methodological approaches for the selection of appropriate SUDS/BMP systems for treatment of road runoff pollution; use of performance criteria as a basis for SUDS/BMP site selection and design
Adoption by NRAs of generic spreadsheet matrix Decision Support System (DSS) approaches for the selection of appropriate site highway runoff/pollutant treatment controls	Confirmation that benchmarked quantitative criteria represent authentic comparisons between different drainage control systems; prediction of SUDS/BMP suitability based on treatment performance capabilities; acceptance that the use of a DSS offers more user-friendly dissemination and understanding of proposed highway drainage design and operation. The Decision Support Systems developed represent initial guidance and need to be supplemented by other factors that a road designer need to take into consideration (e.g. is the road in a cutting or embankment; does the presence of a karstic environment limit the ability to discharge to a stream/river).
Development of national guidelines specifically for the treatment of drainage from road construction sites	Road construction sites differ significantly from building development sites (e.g. in terms of geographical scale, the types of pollutants produced, the runoff volumes generated) and therefore specific guidance would be beneficial.

Table 3.3. Topics requiring further research

Research Area	Beneficial outcomes
Methods for establishing and upgrading road runoff treatment systems in existing road networks	Foster applied research activities in order to generate a solid knowledge base and to realize established and innovative solutions; enable old highways/roads to cope with (new) water protection legislation (such as the Water Framework Directive).
Attribution and quantification of highway source pollutants to observed runoff concentrations and loads	Provision of a better understanding of 'on-highway' pollutant source processes and attributions in relation to observed runoff concentrations; development of an improved database to support appropriate selection of treatment systems to mitigate highway runoff pollutant loadings
Nature and validity of site specificity associated with road runoff pollutant concentrations	The gaining of better knowledge and understanding of the controlling factors relating to site, traffic and storm event characteristics; identification of the principal interacting and interfering variables that underlie site specificity
Quantitative discrimination between source exhaust and non-exhaust emissions (NEE) of pollutants	Providing reliable quantification of the relative contribution of NEE to total road runoff pollutant concentrations; defining the relative contributions and significance of non-highway dry/wet aerial deposition processes to overall highway runoff pollutant loadings; increased knowledge of dispersion and depositional potential of particulate matter as related to particle size, meteorological conditions, landuse etc.
Generic viability of current pollutant source predictive modelling approaches	Improvement of existing generalised relationships between source properties/characteristics and runoff concentrations; development of alternative modelling approaches based on pollutant emission factors and local traffic characteristics and operational modes; increased accuracy in the estimation of site EMC/SMC values; supporting better and more robust risk and vulnerability assessment
Monitoring and measurement of MPs and OMPs in road runoff and evaluation of their potential receiving water toxicity	Development of more accurate and sophisticated analytical techniques for reliably determining MP and OMP levels in road runoff; reduction of uncertainties associated with MP/OMP toxicity values (PEC/PNEC) and more accurate estimation of likely receiving waterbody impacts; an improved knowledge of the specific nature and composition of MP/OMP source contributions; distribution in road dusts, road runoff and adjacent soils; obtaining of more reliable information on relationships of MPs/OMPs to local geographic and climatic variables; collection of improved data to evaluate the relative effectiveness of differing SUDS/BMPs for treatment of MPs and OMPs; the contribution and significance of tyres, brakes, vehicle coatings and corrosion products to total MP/OMP loads
Road salting modelling and application technologies to guide SUDS/BMP treatment	Development of more robust modelling approaches to accurately predict road runoff salt concentrations and compilation of mass balance flows for differing site conditions; determination of optimal application rates and technologies for road salting operations including future roles of road sensors, solution spraying, knowledge transfer etc Impact assessment of chloride-based road salts on adjacent soil structures and mobilisation processes, particularly where associated with infiltration drainage systems; support for the provision of appropriate treatment and management approaches to achieve appropriate balance between road safety and environmental impact concerns
Monitoring and measurement of the pollutant loadings generated during highway construction	Support development of evidence-based highway construction road runoff guidelines
NRA highway drainage management strategy and environmental sustainability	Increase the potential for highway drainage design and operation to become more integrated with wider catchment bio-sustainability and community environment; identification of the role of highway SUDS/BMPs in the wider catchment environmental perspective and achievement of viable eco-corridors; contribution of highway drainage to GI/LID management strategies and development of multi-functional, multi-party collaboration to achieve fully sustainable approaches

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Appendix 1: List of deliverables (by report title) produced by the three projects

MICROPROOF deliverables

M1.1: Review of literature on organic micropollutants, microplastics and associated substances in road run-off.

M1.2: Review of available measurements of organic micropollutants, microplastics and associated substances in road run-off.

M1.3: Combined reviews of literature and measurements of organic micropollutants, microplastics and associated substances in road run-off.

M2.1: Pathways of organic micropollutants and microplastics in road borders.

M2.2: List of potential predicted environmental concentrations for microplastics and OMPs.

M3.1: Environmental Risk Assessment Second draft.

M4.1: Processes and unit operations for road runoff management.

M4.2: Efficiency of treatment systems.

M4.3. Decisions support system as an Excel file.

M4.4: Decision support scheme based on the risk assessment and the treatment efficiencies.

M5.6: Sources, fate and treatment of microplastics and organic micropollutants in road transport.

M6.6: Measurements of organic micropollutants, microplastics and associated substances from road transport.

LUNT deliverables

L1.1: A review of literature on de-icing salt application.

L1.2: Questionnaire among the NRAs – road salt application

L2.1: A review of current vulnerability classification methods used by the NRAs.

L2.2: A method to classify the vulnerability of European water bodies for road salts taking into account chemical and biological impacts.

L3.1: Available methods for treatment and/or prevention of de-icing salts impacts.

L3.2: Cost-benefit analysis and alternative de-icers.

PROPER deliverables

P1.1: Prediction of pollutant loads and concentrations in road runoff. Literature review on road runoff pollution on Europe.

P1.2: Prediction of pollutant loads and concentrations in road runoff Critical review of the tools to predict road runoff.

P1.3: Prediction of pollutant loads and concentrations in road runoff. Road runoff monitoring data and representative sites.

P1.4: Prediction of pollutant loads and concentrations in road runoff. Assessment of tools to predict road runoff pollution.

P1.5: Prediction of pollutant loads and concentrations in road runoff. State of the art of models used for emission calculations and air quality assessment.

P2.1: A review of current knowledge on the vulnerability of European surface water and groundwater to road related pollution, together with a critique of related assessment tools.

P2.2: Construction, operation and maintenance of roads: parameters to assess surface and ground water vulnerabilities and associated risks.

P2.3: Vulnerability of water bodies and risk assessment**:** Evaluation of International, European and national legislative frameworks and approaches.

P2.4: An evaluation of 'real world' vulnerability assessments of surface and ground water bodies to road-related pollution: case study database and critique to identify knowledge gaps.

P2.5: Development of a user-friendly decision-support tool to assess receiving water vulnerability to highway traffic pollution.

P3.1: Literature Review on Blue-Green Treatment Solutions.

P3.2: Sustainable assessment of measures and treatment systems for road runoffs: Survey of guidelines.

P3.3: A decision support system for predicting appropriate treatment devices for highway runoff.

P3.4 PROPER decision support system: user guide.

P3.5 PROPER decision support system: technical manual

P3.6 Case studies and practical examples

P4.1 Literature review on treatment of runoff from construction sites

P4.2 Guidelines for treatment systems for construction works

Appendix 2. An overview of national guidelines for mitigating road runoff and which consider the quality of surrounding water bodies during road construction and operation.

Germany

At the German national level there are two major guidelines that cover the planning phase, but give also advice for the construction and operation phases respectively. For non-urban roads, the RAS-Ew requires infiltration of the road runoff wherever possible. A revised version (REwS) is currently under preparation and will be published in 2021. Here even more focus is directed to widespread infiltration at the road bank, and scientific input from the last decade concerning pollutant retention in road banks with high bearing capacity, soils and soil filters has been integrated.

Additional measures may be necessary for road construction in drinking water protection areas, especially concerning risk of spillage. These measures as well as the factors influencing choice and design of the measures are described in the RiStWag. For roads having been built before a drinking water protection area was designated, the 'Hinweise für Maßnahmen an bestehenden Straßen in Wasserschutzgebieten ("BeStWag", FGSV 1993)', give hints for priorization of measures depending on the risk as well as suggestions for adaption of traffic related and constructional measures. This guideline is currently being revised.

Control and maintenance of treatment facilities including widespread infiltration over the road bank are described in H KWES.

- Drainage systems including natural and technical treatment facilities are described in the technical guidelines "Richtlinien für die Anlage von Strassen – Teil: Entwässerung (RAS-Ew, FGSV, 2005)" (revised as REwS: Richtlinien für die Entwässerung von Straßen. in preparation; announced for 2021 to replace RAS Ew 2005. Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV).
- Drainage systems including treatment facilities for areas of drinking water protection are described in "Richtlinien für bautechnische Massnahmen an Strassen in Wasserschutzgebieten (RiStWag) (FGSV, 2016)".
- Hinweise zur Kontrolle und Wartung von Entwässerungseinrichtungen an Straßen außerhalb geschlossener Ortslagen (H KWES). FGSV 441, 2011.

Sweden

The Swedish Transport Administration (STA) advice on handling runoff water is described in: "Stormwater - Advice and recommendations for the selection of environmental actions" (STA document Trafikverket 2011:112). The STA and its consultants use this publication only internally. Other technical documents are "Technical requirements and advice for Drainage design" (Trafikverket, TRVINFRA-00231). This document is mainly used by consultants. There is also a handbook for maintenance of open stormwater facilities "Open stormwater facilities – A manual for inspection and maintenance" (Trafikverket 2015:147). It is an update of "maintenance of open storm water facilities" in Trafikverket (2008). There is also a STA handbook called "Surface and groundwater protection, risk assessment and risk management" (Trafikverket 2020:171), which focus mainly on risk of spillage and pollution due to traffic accidents. In addition to the Swedish Road Administration's own documents there is a "Draft guideline from 2009 for stormwater discharges" drafted by a "Stormwater Network of Consultants and Officials" from different municipalities in the Stockholm area. This document has a direct influence on the practice of municipalities although it has never been certified. The document provides guidance on management of stormwater depending on the sensitivity of the receiving waterbody. In the absence of other governing documents, it has since been used as a reference. At least three municipalities have also developed their own guidelines in recent years.

Norway

The Norwegian Public Roads Administration (NPRA) has several technical handbooks for road constructions, where stormwater management and dimensioning of treatment facilities is included. The NRPA research and development programme “Nordic Road Water (NORWAT) (2012-2016)” contributed to new knowledge on water quality issues which has been implemented in the handbook. Recent guidelines on when to treat water runoff is decided based on AADT and the vulnerability of the recipient. Vulnerability assessment can be performed by a tool developed in the NORWAT programme, that includes vulnerability assessments based on the Water Framework Directive and the Nature Diversity Act. Issues regarding impact on water quality are also part of the impact assessment in the earlier phases of the planning (e.g. municipal sub-plan and zoning-plan) as well as during operation and maintenance.

Austria

The Austrian “Autobahn- und Schnellstraßen-Finanzierungs-Aktiengesellschaft (ASFINAG)“ considers the (OEWAV regulation, Regelblatt 25) as providing guidelines and technical instructions for planners (OEWAV, 2002). The guideline suggests that runoff water originating from highways, defined as roads having an AADT higher than 15000 vehicles per day, should be collected separately and, if possible, purified before being discharged into rivers.

Switzerland

In Switzerland, permitting procedures follow the national road law; and this includes the rebuilding of a national road (construction), the structural modification of an existing national road (expansion), and maintenance practices. Responsibilities for construction and expansion include that national road projects are approved by the Federal Council, the project documents are governed by the Swiss Confederations "National Road Ordinance” and national road projects have to be approved by the Federal Department of the Environment (DETEC). The documents necessary for these permits are available in the project dossier. The cantonal environmental protection and water protection departments advise the decision-making authorities. The Federal Office for the Environment (FOEN) assesses the environmental compatibility of the national road project. The Cantons have to be involved early in the process. The Federal Road Office (ASTRA) prepares the necessary documentation and contacts the related cantonal authorities. DETEC generally delegates the implementation of the requirements and their control to ASTRA. Maintenance projects are approved in accordance with ASTRA. In fulfilling this task, ASTRA is also responsible for the implementation of the Environmental Protection Act and the Water Protection Act. Maintenance of national roads is carried out in accordance with a Maintenance Planning document. This planning is used for long-term preservation of the structure of national roads. Conservation projects usually include expansion and maintenance. The approval procedures are based on the above.

The Netherlands

The EU Water framework directive is translated into national legislation (*Waterwet* and *Besluit lozen buiten inrichtingen*). The general policy of the Dutch Ministry of Infrastructure and water management is to remove the bulk of the pollution present in the run-off (As Low As Reasonably Achievable, also known as the ALARA-principle). The specific policy regarding run-off for de Dutch NRA is documented in an “executive framework run-off” (*Kader Afstromend Wegwater*, see: http://publicaties.minienm.nl/documenten/kader). This framework ranks the preferential practices in regard to dealing with run-off in the following order:

1. Use a top layer of porous asphalt together with roadside infiltration in the verge;

2. If roadside infiltration is not possible, an indirect discharge to regional surface water through an infiltration or an retention ditch/basin is required. The overflow from all these ditches/basins is designed to only discharge water to the regional surface water under extreme conditions (e.g. heavy rain showers);
3. Short bridges and viaducts discharge their run-off to an infiltration or an retention basin. Long bridges over rivers and/or estuaries discharge their run-off to an infiltration or a retention basin located on the floodplain, or even directly into the surface water below, if there is technically and/or financially no other alternative;
4. All rainwater on rest stops passes through an oil separator before being discharged to the regional surface water system.

Ireland

The Irish National Roads Authority, which now uses the name Transport Infrastructure Ireland (TII) for operational purposes, published *Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes* in 2008 (available at: https://www.tii.ie/technical-services/environment/planning/Guidelines-on-Procedures-for-Assessment-and-Treatment-of-Geology-Hydrology-and-Hydrogeology-for-National-Road-Schemes.pdf). Whilst this document is somewhat dated at this point, it still contains useful information and continues to be applied in the planning of national road projects. TII is currently developing a new standards document that will deal with water impact assessment, which will partly supersede this latter document. TII has also published a suite of standards documents that cover the topic of drainage. These are available for download at: https://www.tiipublications.ie/

Of particular note, TII has published:

- DN-DNG-03065 *Road Drainage and the Water Environment*
- DN-DNG-03022 *Drainage Systems for National Roads*

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