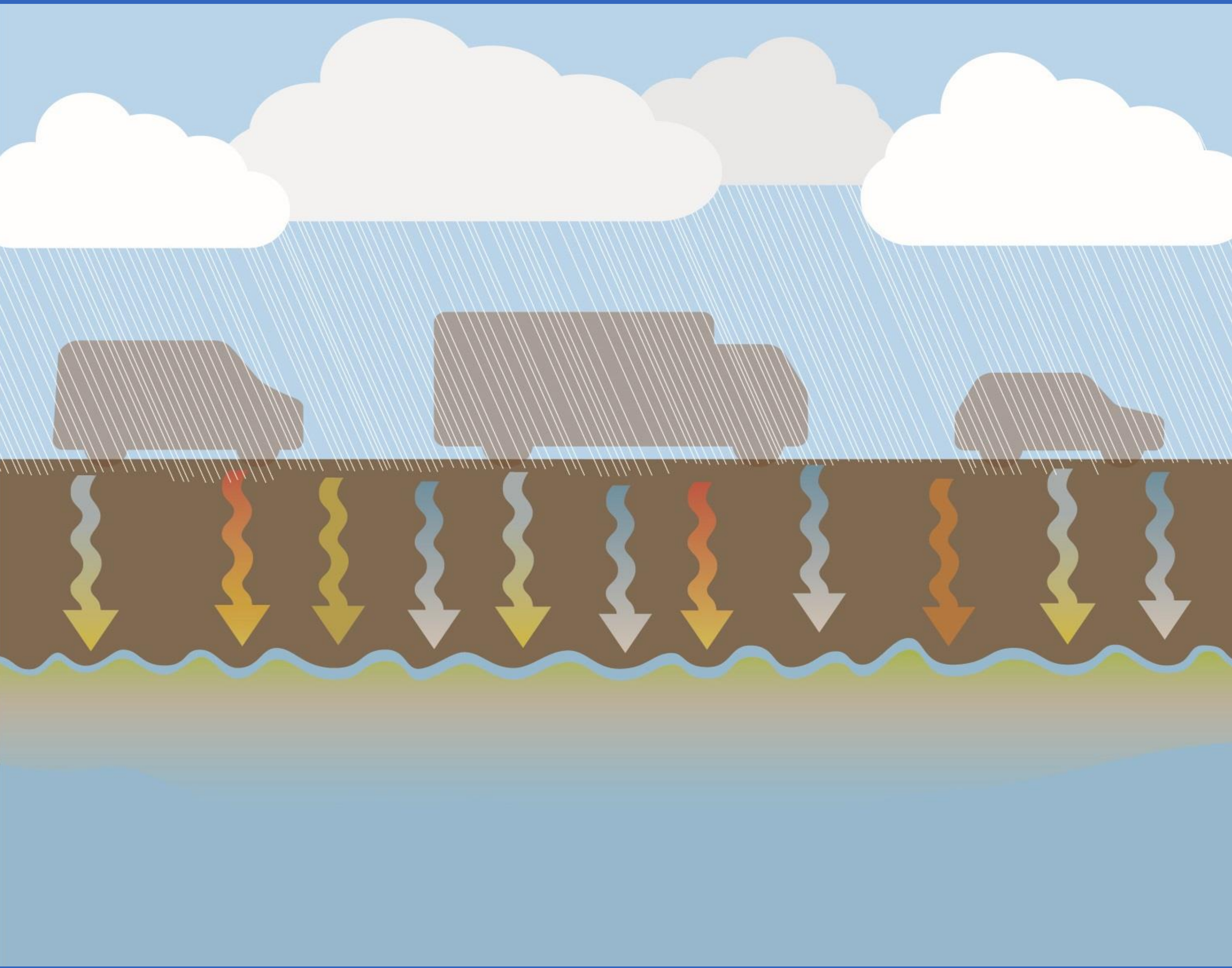
Conférence Européenne
des Directeurs des Routes

Conference of European
Directors of Roads

Management of contaminated runoff water: current practice and future research needs



April 2016

Author:
Dr Sondre Meland, **Norwegian Public Roads Administration**

With contributions from the following people and countries:

Country	Name and organisation	Position/field of experience
Austria	Mr Roland Gschier (Austrian Ministry for Transport, Innovation and Technology)	Technical co-ordinator for environmental impact assessment, thematic priority water quality
	Mr Heimo Berghold (ASFINAG)	Head of Maintenance Service at ASFINAG Environmental and natural hazard protection
	Ms Astrid Traisch (ASFINAG)	Environmental specialist at ASFINAG Environmental and natural hazard protection
Denmark	Mr Ulrik Mörch Jensen (Danish Road Directorate)	MSc Environmental engineering, Danish NRA
Ireland	Mr Peter Walsh (Transport Infrastructure Ireland)	Chartered Civil Engineer and Regional Manager for the Irish National Roads Authority
Italy	Mr Alessandro Mita (Italian Autonomous National Roads Corporation)	Civil Hydraulic Engineer, technical official for the National Autonomous Roads Corporation (General Direction)
Norway	Ms Kjersti Wike Kronvall (Norwegian Public Roads Administration)	Senior Engineer, MSc Limnology in the Environmental Assessment Section
	Dr Hedda Vikan (Norwegian Public Roads Administration)	Senior Principal Engineer, PhD Inorganic Chemistry in the Tunnelling and Materials Section
	Dr Sondre Meland (Norwegian Public Roads Administration)	Senior Principal Engineer, PhD Ecotoxicology in the Environmental Assessment Section
Sweden	Mr Björn Sundqvist (Trafikverket)	National Coordinator Water, MSc Quaternary Geologist, Environmental specialist
	Mr Thomas Gerenstein (Trafikverket)	Environmental specialist, MSc
Switzerland	Mr Adrian Gloor (Swiss Federal Roads Office)	Chemist FH, Authority of Major Accidents Ordinance (FEDRO)
Germany*	Dr Birgit Kocher (BASt, Federal Highway Research Institute)	Mr Jürgen Roth (DEGES, Deutsche Einheit Fernstraßenplanungs- und -bau GmbH)
Poland*	Ms Monika Hardej (GDDKiA)	Mr Jacek Wojtowicz (GDDKiA)
UK*	Mr Mike Whitehead (Highways England)	Mr Steve Cox (Ramboll)

* Participated in the workshop in Stockholm, Sweden, January 2015

Illustration front page: Jon Opseth, NPRA

Approved by the CEDR Governing Board on 20 April 2016
Edited and published by CEDR's Secretariat
ISBN: 979-10-93321-18-9

Executive summary

Transport and mobility are fundamental to modern society. However, roads pervade the landscape, and their short- and long-term physical, chemical, and biological impacts may harm both public health and the environment. For example, increased traffic loadings and the construction of new roads may pose a serious threat to the aquatic environment, for instance because of contaminated runoff. For this reason, awareness of environmental constraints is important, which is why the reduction of pollution is a key challenge for national road administrations (NRAs).

The EU Water Framework Directive (WFD) aims to protect and improve the ecological status of water bodies in order to promote sustainable watershed use. This requires that 'good status' should be achieved for all surface and groundwater bodies by 2015 or 2027 at the latest. Although much effort has been made to meet the objectives of the WFD, 47 per cent of EU surface waters have still not achieved good ecological status. Runoff water from the construction and operation of roads contains a plethora of chemicals including particles, nutrients, salts, metals, and persistent organic pollutants (POPs). Consequently, NRAs must ensure that their water management practices meet the requirements of the WFD, thereby ensuring sustainable development of the road network.

A CEDR task group, TG I5 (Water Quality), led by Norway and with members from Austria, Denmark, Ireland, Italy, Sweden, and Switzerland was formed in 2013. The group sought to provide answers to the following questions:
1 When should contaminated runoff water be treated to meet the requirements in relevant EU directives (e.g. the WFD)?
2 What is the best practice when treatment is mandatory?
3 What will the research needs on these matters be within the next decade?

The work was divided into two subtasks;
1 A state-of-the art report (SoAR), covering questions 1 and 2.
2 Research needs, covering question 3.

The present report compiles the results of both subtasks and aims to review current practice regarding the management of contaminated runoff water during the planning, construction, and operation of roads by European NRAs. It also examines whether current management is compliant with the requirements of the WFD. Direct or indirect impacts on water bodies of a more physical character (e.g. landscape damages, canalisation etc.), water quantity, and climate change were not included in this work. However, it should be stressed that these aspects are also highly relevant in the WFD. The report also presents future research needs. The content of this report is based on findings and information gained through discussions during meetings, country-specific mini-reports on these matters, and a workshop with invited NRA experts from Germany, Poland, and the UK. In short, this work is not a comprehensive review of grey literature or articles published in peer-review scientific journals.

The TG's review shows that all countries need to address environmental issues such as water quality when planning, building, and operating the road network in order to meet the requirements of environmental authorities and national and international regulations such as the WFD.

When planning and building, all countries conduct Environmental Impact Assessments (EIAs) or similar assessments to prevent pollution and protect waters against pollution. However, only a few countries seem to have any standard guidelines on these matters. In addition, there is a tradition in most countries of making the building contractor accountable for adopting proper measures to meet the requirements set by the NRAs themselves or by the environmental authorities. Various measures are used to avoid unintended pollution, and low-cost treatment systems are preferred. However, the fact that there is little data on or experience of how these treatment systems perform on site is a cause for concern. Moreover, the environmental consequences of road construction on the aquatic environment are poorly described in scientific literature.

The decision as to whether to treat road runoff or not appears to be based mainly on traffic density, normally within the range of 10,000–15,000 vehicles/day. The rationale behind the use of ADT (Annual Daily Traffic) is that there is a linear relationship between the number of vehicles and pollution loadings and concentration in the runoff water. However, this is an over-simplification as the correlation between ADT and pollution concentrations has proved to be rather weak. The use of ADT is, therefore, probably more of a 'precautionary principle' than based on sound science. We believe that this can frequently result in an over-provision of measures to mitigate perceived negative impacts and a misdirection of the limited resources available for the protection of water bodies (under-provision may also occur, but probably to lesser extent). In contrast to this, the HAWRAT (Highways Agency Water Risk Assessment Tool), which was developed in the UK and is used there, is based on data obtained from an extensive research programme. In short, HAWRAT appears to be the only evidence-based risk assessment tool that takes into account biological considerations in combination with hydraulics and traffic characteristics. However, it should be stressed that this tool is also encumbered with uncertainties regarding factors such as traffic and toxicity-derived benchmarks. Nevertheless, this approach is significantly more accurate than using a fixed ADT benchmark.

In addition to normal road runoff water, runoff from tunnel washes is of concern as it contains high loadings and concentrations of pollutants including detergents. Tunnel wash water may thus be considered a hot-spot that should not be discharged untreated. The present situation is, however, that some NRAs still discharge contaminated wash water untreated. Finally, road salt consumption is also of concern, not only in the Nordic countries but also in other European countries. This is because there is growing evidence that highly soluble and mobile chlorides impair water bodies both chemically and biologically.

Currently, there is a broad acceptance that road runoff may impair receiving waters. This has led to a shift from conventional drainage systems towards more sustainable blue-green solutions, also known as Sustainable Urban Drainage Systems (SUDS) or Best Management Practice (BMPs). Several systems exist, and countries appear to differ slightly in their preferences. Some use infiltration systems, ponds, or basins/tanks, while others prefer a combination of sedimentation and infiltration. The latter may be preferable as it retains and treats particle-associated pollutants as well as dissolved pollutants. The drawback to this system is that it takes up a lot of space. This has resulted in the use of more technical systems that require less space. Larger centralised treatment plants are also used for reasons of available space and the assumption that operation and maintenance costs are lower. It should be stressed that no one overall treatment method is superior to all others, and the Best Available Technology (BAT) should be considered site specific.

Based on the present review, it appears that Austria, Germany and Switzerland have an extended toolbox of treatment methods compared with the Nordic countries and Ireland. Tunnel wash water is normally treated using sedimentation basins and/or ponds. In some cases, advanced treatment involving filtration and flocculation chemicals is used. In contrast, chlorides from road salt are not treated due to its high solubility and mobility. In fact, road salt may hamper the various treatment processes and reduce overall treatment performance. Despite major investment in the construction of treatment systems, there are indications that the operation and maintenance of such facilities are being neglected, which may result in poor treatment and even in the breakdown of the system. In addition, there are still uncertainties regarding their performance and functionality, and a lack of reliable cost-benefit analyses relating to the construction, operation, and maintenance of various treatment systems.

Based on the present review, we conclude that all countries need to address water quality when planning, building and operating roads in order to meet the requirements of environmental authorities and regulations such as the WFD. However, the overarching goal of 'good ecological and chemical status' stated in the WFD relates generally to the protection of water bodies without making a specific reference to road runoff. It is therefore difficult to conclude whether current NRA water management practices are compliant with the WFD. However, the inclusion of measures and the use of Best Available Technologies (BATs) is often considered a pragmatic approach to solving a problem. It should also be stressed that the present report only considers chemical impacts; physical impacts on water bodies are probably just as important when it comes to meeting the requirements of the WFD.

To conclude, we recommend that the NRAs' engagement in the WFD and the accompanying RBMPs (River Basin Management Plans) increases and that the NRAs work with environmental agencies at national or European level to develop a proportionate design response to the risk presented to water quality by road runoff. This proportionate design response should not be confined to proposed road developments but to the entire existing national road networks, and a programme of retrofitting treatment facilities should be developed, starting with the worst offenders, which are probably tunnel wash water and road salt. The TG suggests five ways of taking this forward:

1 NRAs should work with environmental agencies at national or European level to initiate and develop a common understanding of when road runoff should be treated.
2 NRAs should improve water management by developing guidelines for both the construction and operation phases.
3 NRAs should challenge car manufacturers and related industries to use less hazardous substances in production as vehicles are one of the most significant sources of pollutants present in road runoff.
4 NRAs should initiate and conduct research that will help improve water management in terms of meeting the requirements of the WFD and other relevant regulations/directives.
5 The NRAs and CEDR should continue the work started in SP3 in SP4, as water management will remain an important issue at both national and European level.

All five 'ways forward' could be adopted at both national and/or European level. If the NRAs decide to adopt them at European level, CEDR could initiate collaboration with the European Environment

Agency. We believe that the suggested ways forward would significantly improve decision-making in terms of when and how to treat road runoff. It does not imply that the NRAs can reduce or increase the costs related to water management, but it would ensure that available money is used more efficiently in terms of *when* and *where* road runoff is treated. This would help make transportation greener, thereby reducing its negative impacts on the environment and key assets such as water and ecosystems. It would also be in line with current European transport policy.

Abbreviations

Word	Description
ADT	Annual Daily Traffic
ASF_{63}	Measure of suspended solids
BAT	Best Available Technology
BMP	Best Management Practice
CEDR	Conference of European Directors of Roads
EC	European Commission
EEA	European Economic Area
EFTA	European Free Trade Association
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EMP	Environmental Management Plan
EOP	Environmental Operating Plan
EQS	Environmental Quality Standard
ES	Ecosystem Services
ESA	Ecosystem Services Assessment
GD	Groundwater Directive
GIS	Geographic Information System
HAWRAT	Highways Agency Water Risk Assessment Tool
HCl	hydrochloric acid
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Analysis
NaCl	sodium chloride
NIS	Natura Impact Statement
NORWAT	Nordic Road Water
NRA	National Road Administration
PAH	polycyclic aromatic hydrocarbons
PAX	poly-aluminium chloride
PoMs	Programmes of Measures
QA	Quality Assurance
RBMP	River Basin Management Plan
R&D	Research and Development
SAC	Special Areas of Conservation
SEA	Strategic Environmental Assessment
SoAR	state-of-the-art-report
SP1-4	Strategic Plan Nos. 1–4
SPA	Special Protection Areas
SUDS	Sustainable Urban Drainage Systems
TG	task group
TSS	total suspended solids
WFD	EU Water Framework Directive
WTP	Wastewater Treatment Plant

Table of contents

1 Introduction and definition of the issue

1.1 Purpose

1.1.1 CEDR and Strategic Plan 3

The Conference of European Directors of Roads (CEDR) is a forum for the exchange of experience and information and the analysis and discussion of all road-related issues at European level (Egger, 2013). This includes topics such as infrastructure, infrastructure management, traffic and transport, financing, legal and economic problems, safety, environment, and research.

Having successfully completed two strategic plans (SP1 and SP2), a third strategic plan was launched in May 2013, covering the period 2013–2017. The focus of SP3 is on the present and future challenges faced by national road administrations. According to SP3, awareness of environmental constraints is important. Pollution reduction is, therefore, one of the key challenges in the present SP period. This awareness is in line with the vision outlined in the EU Commission's White Paper on European transport (European Comission, 2011) which says that '…transport has to use less and cleaner energy, better exploit a modern infrastructure and reduce its negative impact on the environment and key natural assets like water, land and ecosystems'. It was in this context that a task group TG I5 (Water Quality) was set up to work on the issue of 'contaminated runoffs during building and operating roads'. A summary of the task and the goals to be achieved by the TG are given in Figure 1.

Summary of the task

Increased traffic loadings and building of roads in Europe during the last decades may pose a serious threat to vulnerable water bodies. This task group will investigate how to protect water bodies from contaminated runoffs originating form building and operating roads and thereby mitigating chemical and biological perturbations on aquatic ecosystems. This is very much in accordance with the EU Water Framework Directive which commits European Union member states to achieve good qualitative and quantitative status of all water bodies. The TG will only focus on chemical water pollution, including effects of water borne solid particles. Physical landscape damages and effects caused by climate change will not be reviewed.

Goals to be achieved

This task group will be focusing on means to mitigate negative impacts on water quality during planning, building and operating the road network. Key questions are:

- When should contaminated runoff be treated to meet the requirements in relevant EU directives (e.g. the EU Water Framework Directive)?
- What will be the best practice when treatment is mandatory?
- What will be the research needs on these matters within the next decade?

Strategy

The task group will divide the work in two sub-tasks:

<u>Subtask 1: State of the art report</u>
Know-how within the CEDR member states will be gathered and reviewed, primarily within TG members, and secondary within all CEDR members.

<u>Subtask 2: Research needs</u>
Based on the results from subtask 1, the TG will make a report on research needs for the coming years (next decade).

Figure 1: Summary of the task and goals to be achieved by TG I5 (Water Quality), CEDR Strategic Plan 3 2013–2017 (Egger et al, 2013)

1.1.2 Impacts on the aquatic environment resulting from the construction and operation of roads

Transport and mobility are fundamental to our economy and society, being vital for the internal markets and for the quality of life of citizens (European Comission, 2011). Road transportation is a key factor in all this (European Comission, 2012b). However, roads pervade the modern landscape, and their short- and long-term physical, chemical, and biological impacts may harm both the terrestrial and aquatic environment (Angermeier et al., 2004; Wheeler et al., 2005).

Figure 2 contains a conceptual drawing of the temporal and spatial impacts roads may have on the aquatic environment (Angermeier et al., 2004). During construction, habitats may be physically destroyed or disturbed and impaired by particles due to erosion and siltation when vegetation is removed, the soil exposed, and masses moved around in the watershed. In addition to having a direct physical impact on the organisms, particles may have an indirect impact by being a vehicle for various contaminants, which may be taken up by the biota. Finally, chemical pollution may originate on the construction site, being caused by tunnelling work, unintended spill, or the release and mobilisation of naturally occurring metals from rocks (Vikan and Meland, 2013). The environmental impacts of the construction phase may be considered acute alterations that can remain for anything from a limited period of a few days to several years and are present on a local and/or regional spatial scale as outlined in Figure 2. There are, however, exceptions to this rule, for instance leakage from acid waste rock deposits, which may last hundreds of years (Hindar and Nordstrom, 2014).

The environmental impacts of the operational phase are on a similar spatial scale to those of the construction phase. However, the environmental impacts of the operation phase normally spans a much longer time frame (Angermeier et al., 2004). Physical impacts include the alteration of the hydrology and geomorphology of water bodies (Coffin, 2007). For example, increased impervious areas and canalisation of streams will alter the runoff patterns and the water flow in a watershed. Large amounts of particles are transported from the road surface to the aquatic environment, leading to siltation of water bodies, which may cause the physical alteration of habitats and have direct and indirect negative effects on organisms (Coffin, 2007). Road runoff typically contains a wide variety of chemical pollutants originating from vehicles, the road surface, technical infrastructure such as guardrails and traffic signs, maintenance such as tunnel cleaning, de-icing, and vegetation control. In addition, the release of chemical pollutants from accidental spillages may occur (Meland, 2010b). Common pollutants found in road runoff episodes are listed in Table 1, and examples of the concentrations of some traffic-related pollutants are listed in Table 2. Studies conducted in recent decades have shown that chemical pollution from roads may adversely affect the aquatic environment (e.g. Hindar and Nordstrom, 2014; Maltby et al., 1995; Meland et al., 2010).

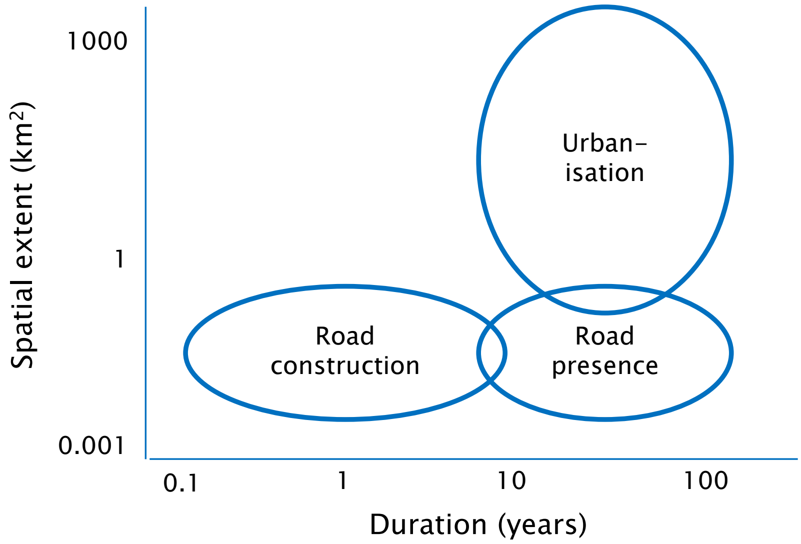


Figure 2: The temporal and spatial extent of impacts caused by road development. Road construction occurs over relatively small time and space scales, while urbanisation occurs over much larger scales (axes are logarithmic). Modified from (Angermeier et al., 2004)

During the construction phase, a variety of measures may be adopted to reduce the risk of causing unintended harm to the aquatic environment. These include erosion control, sedimentation basins, flocculants, and pH-adjustment. These measures are often required by law, and normally, their scale is adapted to suit the size and complexity of the construction site, taking into account the vulnerability of the influenced water bodies. The above-mentioned measures have been utilised for years on many construction projects. It can therefore be assumed that in most cases, sufficient protection of the water bodies is ensured. However, according to Wheeler et al. (2005), the performance and effectiveness of these measures are rarely evaluated, and their risk of failure is seldom considered.

Mitigating peak runoff volumes and reducing pollution loadings and concentrations throughout the long operational phase of a road network is now considered important and is often mandatory both from a regulatory perspective (i.e. regulatory requirements at national level) and for the National Road Administrations (NRAs) responsible for planning, building, and maintaining the road network. Typical measures include sedimentation ponds[1], wetlands, swales, infiltration basins, etc. (Hvitved-Jacobsen et al., 2010). In addition, more advanced and technical treatment measures such as soil filters and other commercially available filters seem to be becoming more popular in some countries.

[1] The nomenclature of various treatment facilities and systems is not consistent throughout the literature, and several names exist for more or less the same type of system. For instance, the terms 'sedimentation pond', 'retention pond', and 'detention pond' are commonly used in literature for the same type of treatment system. The terminology often varies from country to country.

Table 1: Information about road runoff pollutants and their most important sources. The table has been modified. The original table together with references can be found in Meland (2010a)

Source		Contaminant
Vehicle	Brakes	Ba, Cu, Fe, Mo, Na, Ni, Pb, Sb
	Tire (incl. studded tire)	Al, Zn, Ca, Cd, Co, Cu, Mn, Pb, W, hydrocarbons, PAH (pyrene, fluoranthene, benzo(ghi)perylene)
	Catalytic converters	Pt, Pd, Rh
	Vehicle body	Cr, Fe, Zn (steel)
	Combustion	Ag, Ba, Cd, Cr, Co, Mo, Ni, V, Sb, Sr, Zn, PAH (naphthalene), MTBE, BTEX
	Oil and petroleum spill, oil drip, used lubricant oil	PAH
Non-vehicle	Road surface (asphalt, bitumen)	Al, Ca, Fe, K, Mg, Na, Pb, Si, Sr, Ti, PAH
	De-icing and dust suppression	Ca, Mg, Na, Cl, ferro-cyanide (anti-caking agent)
	Road equipment (e.g. guardrails, traffic signs, etc.)	Zn (galvanised steel)
	Detergents used in tunnel wash	Tensides
	Vegetation control	Herbicides

Table 2: Examples of concentrations measured as event mean concentrations (EMC) and runoff loadings of some traffic-related pollutants obtained from a British survey consisting of 340 episodes from 30 different sites with ADT ranging from 5,000–200,000 vehicles/day. Copied from Crabtree et al. (2009) and Highways Agency (2009)

Determinand	**Runoff Concentration**						**Runoff Load**	
	Units	**LOD**	**Min. EMC**	**Mean EMC**	**Median EMC**	**Max. EMC**	**Mean/ 1000m^2**	**Units**
Total Copper	µg/l	0.3	4.00	91.22	42.99	876.80	0.66	g
Dissolved Copper	µg/l	0.3	2.15	31.31	23.30	304.00	0.16	g
Total Zinc	µg/l	0.6	9.73	352.63	140.00	3510.00	2.44	g
Dissolved Zinc	µg/l	0.6	4.99	111.09	58.27	1360.00	0.50	g
Total Cadmium	µg/l	0.01	<0.01	0.63	0.29	5.40	0.00	g
Total Fluoranthene	µg/l	0.01	<0.01	1.02	0.30	12.50	0.01	g
Total Pyrene	µg/l	0.01	<0.01	1.03	0.31	12.50	0.01	g
Total PAHs (Total)	µg/l	0.01	<0.01	7.52	3.33	62.18	0.04	g

1.1.3 The EU Water Framework Directive (WFD)

Although European water legislation has been around since the 1970s, the EU Water Framework Directive (WFD, 2000/60/EC)[2] adopted in year 2000 (European Comission, 2010), is considered ground breaking. The WFD established a legal obligation to protect and restore the quality of European water bodies. Instead of focusing on national or political boundaries, water management in the WFD relies on natural geographical and hydrological formations, i.e. river basins. Other key features include the active involvement of interested parties and the consultation of the public in water management. The main goal of the WFD was to achieve 'good status' for all of Europe's surface waters[3] and groundwater by 2015 or 2027 at the latest. 'Good status' for surface waters implies 'good ecological and chemical status' in terms of low levels of chemical pollutants and healthy ecosystems (Figure 3). 'Good status' for groundwater implies 'good quantitative and chemical status' (daughter directive, Groundwater directive 2006/118/EC). The ecological status of surface waters describes the abundance of aquatic flora and fauna, the availability of nutrients, and aspects such as salinity, temperature, and chemical pollution. Morphological features such as quantity and water flow are also accounted for. The definition of good chemical status includes environmental quality standards (EQSs) set for a range of chemical pollutants of concern (termed 'priority substances' in the WFD (daughter directive, Environmental Quality Standards (EQS) Directive 2013/39/EU)). The list currently contains 45 new and eight previously regulated pollutants, which are bioavailable, toxic, and persistent in the environment. Discharges must be eliminated within 20 years. In addition, other relevant chemical pollutants of regional and/or national concern (e.g. copper (Cu) and Zinc (Zn)) may be included as parameters defining the ecological status (termed 'river basin specific pollutants' in the WFD). These parameters and their respective EQSs are, however, country specific. In addition to achieving good status, prevention of deterioration of the water bodies' existing status is also an essential part of the WFD.

In essence, the WFD implies that member states must identify first the problems and then the solutions (European Comission, 2010). Hence, water quality objectives for every water body need to be defined, and appropriate restoration measures within a given timeline need to be prescribed in a River Basin Management Plan (RBMP) and the accompanying Programmes of Measures (PoMs). This is a holistic approach that protects the whole water body and tackles pressures and risks by means of a coordinated strategy involving all parties. The directive works on the basis of six-year recurring management cycles, the first covering the years 2009–2015. In 2015, the second round of RBMPs was put in place, and by 2019, the WFD will be reviewed and, if necessary, revised. Although the WFD requires all parties to be involved in the RBMPs, the actual participation of the NRAs varies substantially from country to country. For example, the Norwegian and Swedish NRAs have been involved at both national level and in the specific RBMPs, while other NRAs have not been involved at all.

[2] The WFD provides a framework for integrating a number of other pieces of thematic water legislation, known as 'daughter directives'. These include, for example, the Groundwater Directive, the Environmental Quality Standard Directive, the Urban Waste Water Directive, the Nitrates Directive, the Bathing Water Directive, and the Drinking Water Directive (European Comission. Water is for life: How the Water Framework Directive helps safeguard Europe's resources. EC, Luxembourg, 2010, pp. 25.)
[3] A surface water body is a section of a river, a lake, transitional waters, or coastal waters. Transitional waters connect freshwaters such as rivers and marine waters (e.g. estuaries).

Although much effort has been made to meet the objectives of the WFD (i.e. through the RBMPs), much remains to be done. Forty-seven percent of the EU's surface waters had not achieved 'good ecological' status by 2015, which means that a greater effort needs to be made (EEA, 2014). It should be stressed that there is huge uncertainty regarding this figure. In addition, the ecological status and the chemical status are defined as being 'unknown' for more than 15 per cent and 40 per cent of the surface water bodies respectively (European Comission, 2012a). Agricultural activity is emphasised as a key pressure on water quality in the RBMPs. In contrast, the extent to which roads and traffic contribute to the deterioration of European water bodies is rather unclear, which may reflect the apparently low involvement of NRAs in the WFD and the RBMPs.

Figure 3: Illustration of the 'ecological status' in the WFD; 'high' implies 'no' or 'very low' human pressure (reference condition; the benchmark). Quality is assessed by the degree of deviation from the reference condition. 'Good status' means slight deviation, 'Moderate status' means moderate deviation, and so on (copied from European Comission, 2013)

1.2 Scope

The present State-of-the-Art Report (SoAR) describes current practice and approaches to the protection of water bodies in relation to the planning, construction, and operation of roads in several European countries (Subtask 1, see Figure 1). These practices are reviewed in an effort to ascertain if they are appropriate in the context of the requirements of the EU WFD[4]. In addition, future research needs are presented. Finally, suggestions on possible ways forward within these matters are presented at the end of the report. The SoAR is therefore not a comprehensive review of the impact of roads on the aquatic environment. In addition, physical landscape damage and

[4] Other relevant EU directives such as the Habitats Directive (92/43/EEC), the Birds Directive (2009/147/EC), the Environmental Impact Assessment (EIA) Directive (85/337/EEC), and the Strategic Environmental Assessment (SEA) Directive (2001/42/EC) influence the planning, construction, and operational phase of roads but are not further addressed here. The reader is encouraged to read more about these matters in the paper published by Yannopoulos S, Basbas S, Giannopoulou I. Water bodies pollution due to highways stormwater runoff: measures and legislative framework. Global Nest Journal 2013a; 15: 85–92.

effects caused by climate change have not been included[5]. Climate change and adaptation are covered by a different CEDR task group.

1.3 Methodology

A task group (TG I5 (Water Quality)) lead by Norway and comprising members from Austria, Denmark, Ireland, Italy, Sweden, and Switzerland was formed in September 2013 (Figure 4). During its first meeting, the group agreed on a common strategy for the SoAR. It decided that each country would write its own 'SoAR mini-report', which together would form the basis of the SoAR. Because the mini-reports were to be similar in structure and content, a common content list was drawn up for all countries. The output from the mini-reports was then reviewed to identify similarities and differences between the various countries in terms of how they manage contaminated runoff during the planning, construction, and operation of the road network. The TG had representatives from seven countries (originally eight). It realised that the scope and the quality of the SoAR would be enhanced if information from other CEDR member countries was included. It was therefore decided at the TG's third meeting to invite a number of countries to a workshop. The rationale behind organising a workshop instead of the more 'traditional' CEDR questionnaire was the TG belief that the quality of the information gained from a workshop would be better and probably easier to interpret than answers to a questionnaire. For this reason, it was decided to invite experts from Germany, Poland, and the UK (Figure 4). These countries were chosen because the TG wanted to include countries that would complement the countries represented in the TG in terms of geography and population size. It was hoped that this would ensure a more comprehensive review. The workshop was held in Stockholm (Sweden) in January 2015.

The present SoAR is therefore based on findings and information gathered through discussions during meetings, the mini-reports, and the workshop. In addition, a report published by Håøya and Storhaug (2013) in the NORWAT[6] research and development (R&D) programme reviewing water management in 12 countries was used to complement the present work. Although some relevant additional literature was used, this work is not a comprehensive review of grey literature or articles published in peer-review scientific journals.

[5] The TG is aware that climate change such as increased and more intense precipitation is highly likely to have an effect on water quality and organisms' susceptibility to pollutants.
[6] NORWAT (Nordic Road Water) is a four-year R&D programme (2012–2016) run by the Norwegian Public Roads Administration (www.vegvesen.no/norwat).

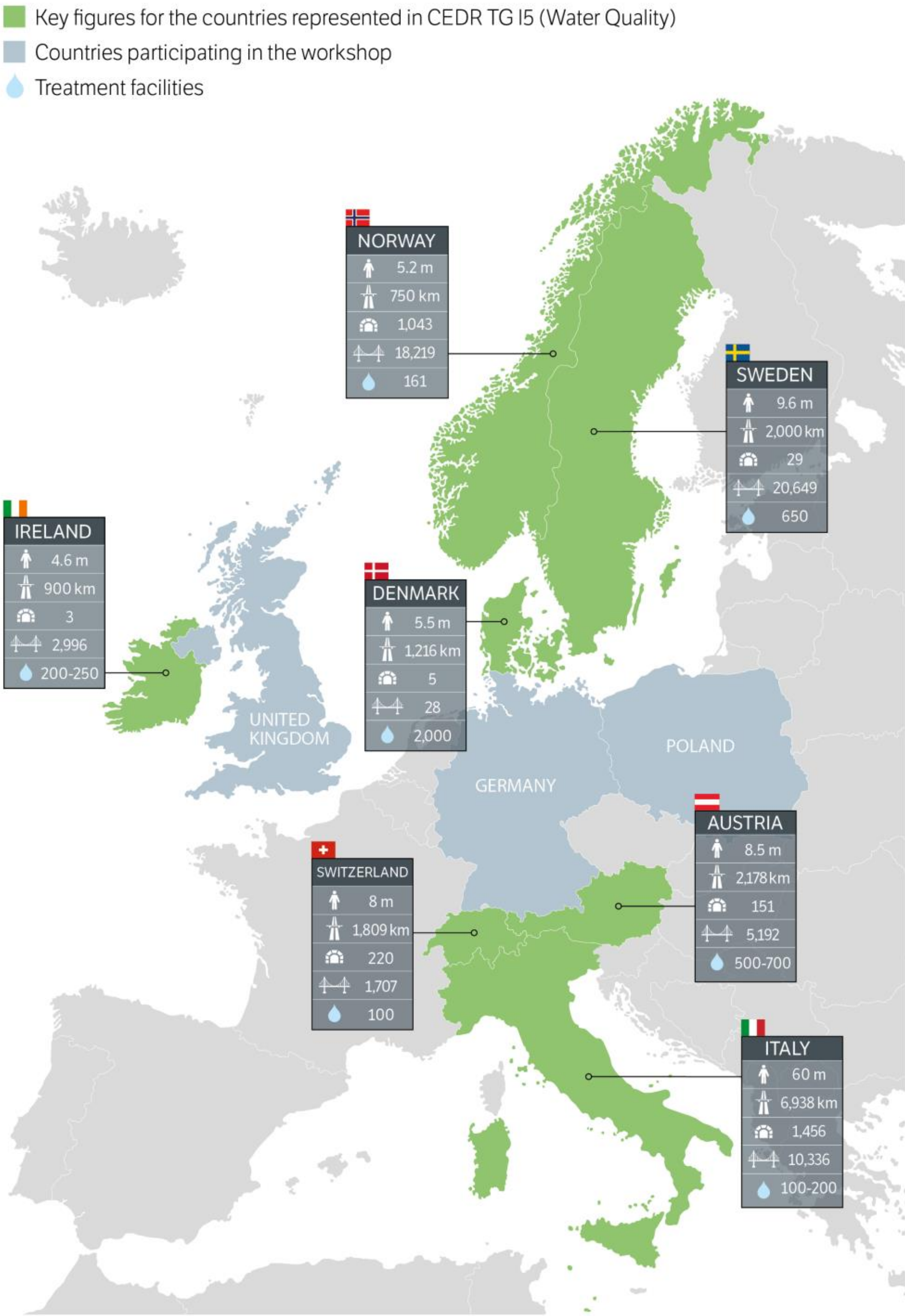


Figure 4: Map showing the CEDR countries with representatives in TG I5 (Water Quality) and those who sent delegates to the workshop in January 2015. Key figures for the various countries are displayed in the grey boxes (Ill: Jon Opseth, NPRA)

2 Results

2.1 Planning, regulations, and steering documents

Each TG member country has a planning process for proposed road developments. The processes require the developer of the proposed road development to produce an Environmental Impact Statement (the output from an Environmental Impact Assessment (EIA Directive 85/337/EEC) and a Natura[7] Impact Statement (NIS) or similar documents). The production of these statements may require extensive studies and research to be conducted in order to predict the environmental impacts of the development beyond reasonable scientific doubt. It should be stressed that these statements focus on biodiversity and not on water quality per se. The statements are used by the planning authority to complete an appropriate assessment and an Environmental Impact Assessment (EIA) of the proposed road development. By way of example, Figure 5 illustrates the planning process in Switzerland.

Austria, Denmark, Ireland, Italy, and Sweden are all members of the EU and therefore all have environmental legislation that is in line with the WFD and daughter directives such as the Groundwater Directive and EQS Directive for priority pollutants. In contrast, Norway and Switzerland are members of the European Free Trade Association (EFTA) and not the EU. Both countries are, however, part of the EU's internal market as a result of their EFTA membership: Norway through the agreement on a European Economic Area (EEA) and Switzerland through a set of bilateral agreements. Norway has integrated the WFD and daughter directives into Norwegian legislation, while Switzerland has not adopted the WFD but has its own set of regulations, which are consistent with the goals of the WFD.

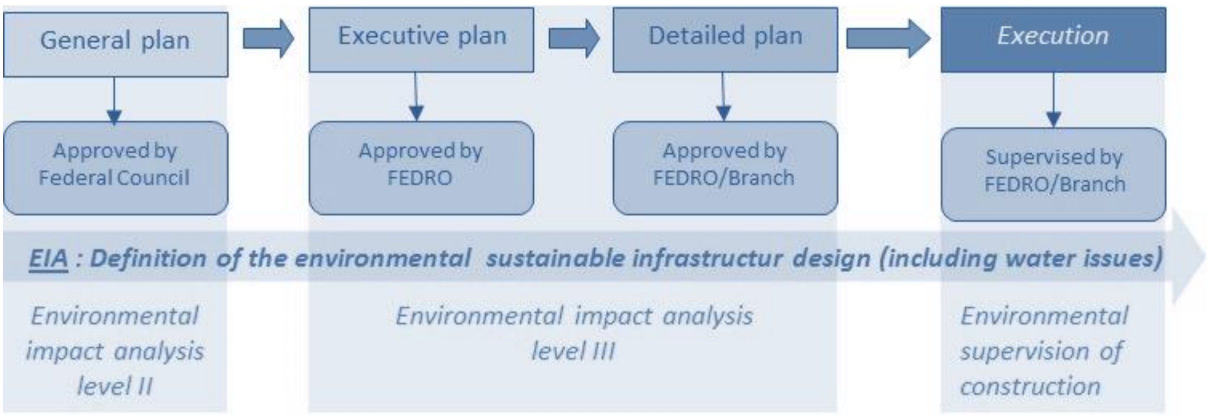


Figure 5: Outline of the planning process in Switzerland

[7] Natura 2000 is the European network of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) designated under Directive 92/43/EEC (the Habitats Directive) and Directive 2009/147/EC (the Birds Directive).

2.2 Road construction

2.2.1 When contaminated runoff is treated

Road construction

Generally, the countries represented in the TG state that water bodies should not be polluted by contaminated runoff episodes during construction. In this respect, the vulnerability of the recipients is considered, and the ecological and chemical status of the recipients is expected to be known from the planning phase. In general, the construction contractor is responsible for minimising the risk of polluting the waters by adopting proper measures and for making sure that these measures function well during the construction period. Despite the fact that all NRAs are obliged to protect surface waters from damage, only a few appear to use guidance documents. For example, Ireland avails of two guidelines Control of Water Pollution from Construction Sites (Ciria C532) (CIRIA, 2001) and Control of Water Pollution from Linear Construction Sites (Ciria C648) (CIRIA, 2006)[8].

The main focus regarding pollutants during construction appears to be on particles, hydrocarbons (oils), nitrogen compounds (e.g. ammonium and ammonia), and pH. In specific cases, naturally occurring metals leached from bedrocks during construction and whenever the recipient is considered vulnerable may also be of concern. In addition, organic pollutants such as PAH's are of concern. The details of the monitoring programme (e.g. sampling frequency, parameters, etc.) and the set of benchmarks vary from project to project. Table 3 contains sample benchmarks from a Swedish road construction project.

Table 3: Benchmarks set for a Swedish road construction project

Parameter	Benchmark
pH	6.5 – 8.5
Hydrocarbons (mg/l)	1.0
Suspended solids (mg/l)	125
Total nitrogen (mg/l)	3.5
Zinc (µg/l)	100
Cadmium (µg/l)	0.7
Copper (µg/l)	40
Lead (µg/l)	20
Chrome (µg/l)	25
Nickel (µg/l)	30
Mercury (µg/l)	0.08
PAH 16 (µg/l)	2

[8] CIRIA (the Construction Industry Research and Information Association) is a neutral, independent, not-for-profit body that links organisations with common interests and facilitates a range of collaborative activities that help improve the industry. It is not an Irish body, but the Irish NRA refers to CIRIA documents in its standards and guiding documents, e.g. in the Irish NRA's Design Manual for Roads and Bridges (DMRB).

Tunnelling

Generally, the risk of causing harm to the aquatic environment is probably higher during tunnelling than during normal road construction work. The reason for this is that tunnelling requires huge volumes of water for drilling and the removal of cuttings. In addition, there is natural leakage from the surrounding rock. For example, a drilling rig may consume 300 l/min (Vikan and Meland, 2013). Contaminants of concern include particles (5,000–10,000 mg/l of total suspended solids (TSS) have been reported in Norwegian tunnelling projects), oil leakage/spillage caused by accidents, high pH caused by cement-based grout and shotcrete (pH 11–12 is common), and elevated nitrogen, ammonium, and ammonia from shards with undetonated explosives (10–15%). The combination of elevated pH and nitrogen may form toxic ammonium. Leakage from natural rock may be a source of acidic runoff, heavy metals, and radionuclides. Alum shale and sulphur containing granites are examples of problematic bedrocks. Grouting chemicals may contain trace amounts of harmful chemicals. Finally, plastic fibre (polypropylene), which is used as reinforcement to shotcrete during tunnelling to secure the rock surface, may unintentionally be transported to surface waters. Plastic fibres are frequently used in sub-sea tunnelling projects in Norway[9]. This is not only a litter problem, but also a problem for organisms, which may eat the plastic. In addition, small plastic particles may be important carriers of pollutants, thus also posing a toxicological risk.

Despite the environmental concern related to contaminants in tunnelling water, none of the NRAs represented in the TG state that they have any benchmarks. Any discharge permits with benchmarks appear to be set locally from case to case. Examples of benchmarks obtained from a Norwegian tunnelling project are presented in Table 4.

Table 4: Examples of benchmarks set for a Norwegian tunnelling project

Parameter	Benchmarks	Comments
Total Suspended Solids (TSS)	100–400 mg/l	Requirements usually apply to discharge water from tunnelling. The treatment method is sedimentation, often in combination with a filter. Requirements for turbidity or clarity are set (on the inside and outside of the silt curtain) for erosion and runoff from the construction site.
pH	8–9	
Total nitrogen / ammonia	5, 10, 15, and 25 µg/l, which correspond to very good, good, moderate, and poor respectively	The class boundaries are stipulated by the Water Framework Directive. Ammonia concentration is controlled by pH. Treatment of ammonium and ammonia are not common, but in some cases venting the system water is recommended.
Hydrocarbons	50 mg/l	Benchmark set for oil emission in sludge.

9 The use of plastic fibres will be banned in Norwegian tunnelling projects from 2016.

Bridge construction

The construction of bridges may involve water during dredging and piling close to waters. Building may also occur in or above the surface water. Contaminants of concern include particles and chemicals used during bridgework (coating chemicals, cement, etc.). Bridge-building may therefore have a negative impact on water quality. The NRAs represented in the TG seem to have no technical guidelines on how to protect the aquatic environment during bridge-building. However, several emphasise that permits are required and environmental authorities (at a municipality or county level) can set benchmarks.

2.2.2 How contaminated runoff is treated

Road construction

The Irish NRA uses settlement ponds, silt nets, channels and ditches, and tanks. Typically, ponds are used in conjunction with ditches and channels. The ditches and channels may include some kind of simple weirs and/or straw bales to enhance the removal of suspended solids. For excavations within 10 m of watercourse, silt fencing is often mandatory. The fence is made of fine mesh netting and approximately 500 mm high. Settlement tanks equipped with baffle tanks are considered more expensive than ponds and other solutions and are therefore used less frequently.

In Italy, there appears to be no standard methods for treating runoff from construction sites. In general, treatment systems should be adopted in those cases where contaminated runoff events are expected. In addition, rainwater/runoff water is conveyed into small units that are able to retain the first 15 minutes of an event ('first flush'[10]) (Figure 6).

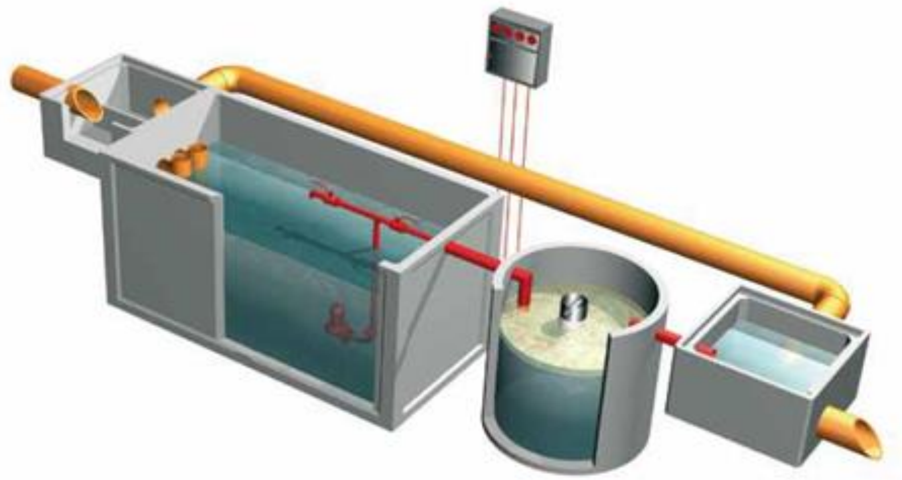


Figure 6: Small tanks used on Italian construction sites to retain the first 15 minutes of a runoff event

[10] The term 'first flush' is a phenomenon that is assigned to the rapid and considerable increase in the pollutant concentrations and/or masses found in the initial phase of a runoff episode with a subsequent rapid decline in concentrations and/or masses. This feature is typical in areas with high percentages of impervious areas such as roads.

Like the Irish NRA, the Austrian NRA uses settlement ponds to remove suspended solids. Normally these systems consist of two ponds in parallel. In addition, oil interceptors are used at parking areas. This is also the current practice in Norway. In addition, flocculation chemicals are occasionally used in some projects where the recipient is considered vulnerable. The Norwegian NRA also utilises silt curtains within the recipient to avoid the unintended spread of particles.

In Switzerland, the main types of treatment are sedimentation, which in some cases may also include flocculation chemicals, oil-absorbing material, and pH- and temperature adjustment. pH-adjustments are performed using CO_2. In addition, oil interceptors and emulsion splitters may be used to reduce the concentrations of oils (hydrocarbons) (Figure 7). The Swiss NRA also protects the ground water using measures such as sealing, which prevent the leaching of hazardous chemicals. Filtration of runoff water with active carbon is also used. Examples of benchmarks for construction site runoff in Switzerland are given in Table 5. The appropriate treatment measures are determined during the EIA, when the size and duration of the project and the vulnerability of the recipients are considered. In bigger construction projects, the contractor is obliged to set up monitoring programmes. Independent contractors carry out these programmes, and the results are presented to the environmental authorities on a regular basis.

Figure 7: Example of a mobile emulsion/flotation splitter used in Switzerland (photo: Swiss Federal Roads Office)

Table 5: Benchmarks for some parameters for construction site runoff in Switzerland

Parameter	Benchmark surface water	Benchmark sewerage
pH-value	6.5–9.0	6.5–9.0
Transparency (clarity)	30 cm	-
Total Suspended Solids	20 mg/l	-
Total hydrocarbons	10 mg/l	20 mg/l

In Sweden, the common practice is to use sedimentation basins in combination with oil interceptors. Sometimes flocculants are used to enhance the sedimentation processes. In addition, various measures to prevent and/or mitigate aquatic pollution caused by accidents or other unintended causes are normally taken. This appears to be common practice in most of the countries in the present study.

Tunnelling

In Switzerland, the current practice is to reuse the drilling water as much as possible. To avoid breakdown or damage to machinery, suspended solids and larger particles must be removed from the drilling water and the pH must be adjusted to an acceptable level. Consequently, the practice of reusing drilling water may be an effective incitement to the contractor to operate the treatment facility properly. Highly polluted drilling water containing high levels of leachate from concrete, undetonated explosives, etc. must be collected and disposed of separately. As outlined in Chapter 2.2.1, high concentrations of nitrogen in tunnelling water are common and may pose a serious threat to the aquatic environment. The Swiss NRA has in the past used local de-nitrification plants involving sodium hypochlorite (NaClO) in an attempt to oxidise high nitrite concentrations. However, its experience is that this type of treatment is too difficult to operate properly on a construction site. In addition, the unintended release of hypochlorite may cause significant harm to the aquatic environment, something that happened during the construction of the Gotthard railway tunnel (Tessin River). Accordingly, the Swiss NRA has stopped all further testing with sodium hypochlorite. None of the other NRAs has any experience with nitrogen treatment. To reduce problems with ammonia, the Swiss NRA uses pH adjustment with CO_2.
Figure 8 shows a treatment system based on sedimentation and pH-adjustment.

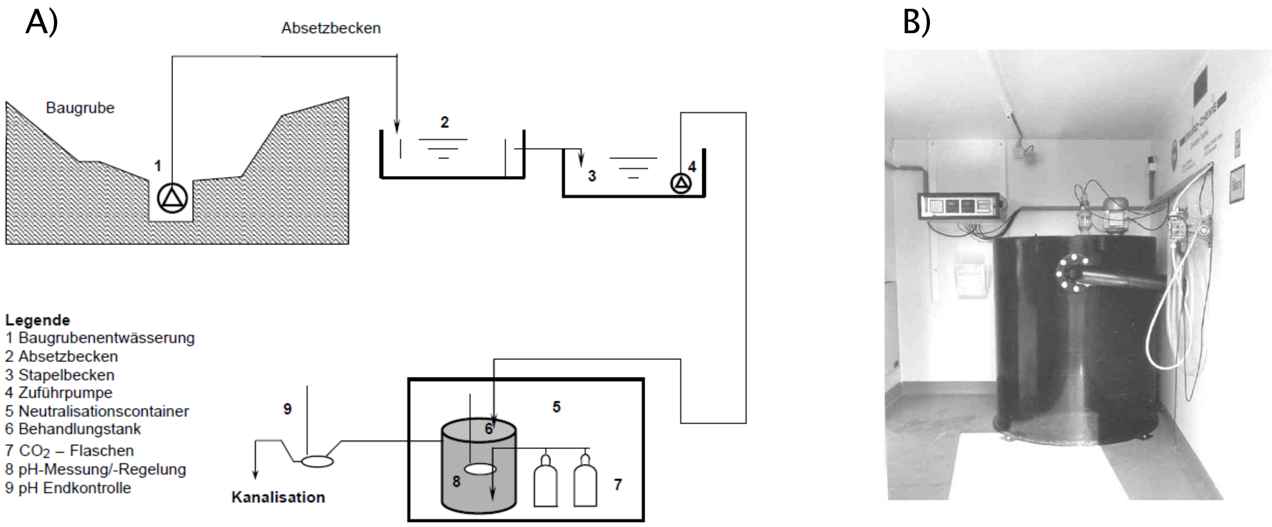


Figure 8: A treatment system combining sedimentation and pH-adjustment used in Switzerland (A). The pH-adjustment stage (B) (photo: Swiss Federal Roads Office)

In Austria, tunnelling water is treated using two sedimentation basins in parallel. If necessary, flocculation chemicals are used to enhance the sedimentation process, and pH-adjustment of the tunnelling water is done using CO_2. As far as the removal of nitrogen is concerned, Austria did consider using ozone (O_3), which is a strong oxidizer, but the complexity and costs of the procedure were considered too high (€100,000–150,000, operational costs excluded). Hydrocarbons are typically removed using oil interceptors. The levels of turbidity, pH, and conductivity in the treated tunnelling water are monitored on-line. Benchmarks are set and whenever these are exceeded, an automatic shutdown occurs, preventing any unintended discharge of tunnelling water.

The Swedish NRA washes blasted rocks to prevent the unintended release of high nitrogen concentrations. The wash water is discharged into a municipal wastewater treatment plant. As in Austria and Switzerland, the pH value of the tunnelling water is adjusted using CO_2. In Sweden, it is also common practice to infiltrate the treated tunnelling water into the ground in order to secure the groundwater level in the influence area. In fact, tunnelling water has previously been used to enhance the water flow in small streams where past activities have reduced normal water flow patterns.

The treatment of tunnelling water in Norway is comparable with that of the other countries (Figure 9). Similar to the Swiss practice, the re-use of drilling water was required in some Norwegian tunnelling projects. However, this is not currently a standard requirement. Contrary to practice in other countries, it is standard practice in Norway to use acid (e.g. HCl) instead of CO_2 for the pH-adjustment of tunnelling water. In an environmental context, the use of acid is not as good a choice as CO_2[11]. This because the risk of overdosing with acid followed by an unintended drop in pH is

[11] The use of CO_2 instead of acids is also beneficial from a work safety perspective.

higher compared with the risk using CO_2. Efforts are, however, being made to include CO_2 in the standard procedure for pH-adjustment.

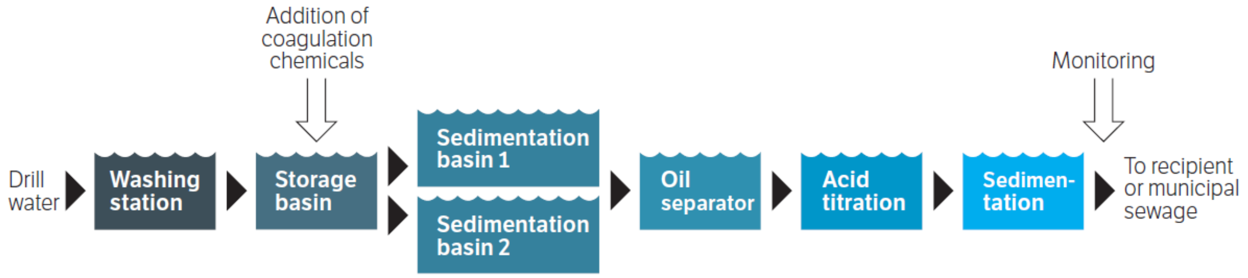


Figure 9: Conceptual flow chart showing the various treatment stages in a Norwegian tunnelling project

Tunnelling projects are not very common in Ireland. However, in previous projects, cyclones have been used to remove particles from the tunnelling water. Similarly, in an on-going Norwegian railway tunnelling project, the contractor has conducted tests using huge centrifuges to separate particles from the water. According to the contractor, the results and experience so far have been promising. In fact, the contractor intends to use this technology in two recently launched road construction projects in Norway.

Bridge construction

The Swiss NRA stresses the importance of doing construction work such as asphalting in dry periods in an effort to avoid the discharge of waterborne pollutants as much as possible. Temporary drainage systems are built for larger construction projects that include bridges. When sandblasting steel bridges (mainly railway bridges), the bridge may be fully enclosed by containment structures, and particles and waste collected and disposed of. Ireland, Sweden, and Norway are aware of siltation as a problem and all three say that silt-traps with an associated buffer strip and silt curtains are important measures.

2.2.3 The operation and maintenance of treatment systems

Contractors operate and maintain the treatment systems and are more or less free to choose whatever system they prefer. In other words, the criteria for the discharged water are set by environmental authorities and/or by the NRA, and the contractor chooses a method/system that meets these criteria. This explains why most countries do not have any specific protocols or guidelines on how to choose systems or how to maintain and operate them. Information on selection, maintenance, and operation is usually outlined in the Environmental Operating Plan (EOP)[12] or Environmental Management Plan (EMP). The exception to this rule is Austria, where such guidelines do exist.

[12] In Ireland, the term 'Environmental Operating Plan (EOP)' is used instead of the term 'Environmental Management Plan (EMP)' as the latter term was connected with Quality Assurance (QA) regulations and caused some confusion.

2.2.4 Costs vs. utility of water treatment systems

As stated in Chapter 2.2.3, contractors are free to choose the treatment system as long as the criteria/benchmarks set in the permits are met. For this reason, it is very difficult to estimate costs vs. utility. However, most of the systems are rather simple (e.g. earth basins) and may be considered low-cost measures.

2.3 Road operation

2.3.1 When contaminated runoff, including tunnel wash water, is treated[13]

Roads

The standard procedure in Norwegian road construction projects is that the decision to treat road runoff is normally made during the EMP process. The environmental authorities (normally at regional (county) level) must approve the EMP. The main factors/indicators leading to the decision to treat road runoff are traffic intensity measured as annual daily traffic (ADT) and the vulnerability of the recipient. Despite this, there are currently neither specific ADT benchmarks nor any clear, objective criteria to decide whether a recipient is susceptible to road runoff or not. For this reason, the decision is often based on the practice in previous projects and the planners' (or the consultants') professional knowledge in these matters. However, some old guidelines and reports contain advice and recommendations, e.g. on emission factors relating to ADT. Norway is currently working to make the decision-making process less subjective. It should be stressed that up until now, the decision to set up a treatment system or not has only been made for new-build projects and not for the existing road network.

In Austria, there is a long tradition of protecting the groundwater that goes back to before the 1980s. In order to protect the groundwater from polluted runoff water, motorway sections within groundwater protection areas were sealed and made impermeable. The runoff water was conveyed out of the protected area and discharged - either untreated or treated using small simple sedimentation basins - into other water bodies. These measures prevented perturbations of the groundwater. Current environmental legislation requires the protection of the aquatic environment, and road projects must have a permit to discharge runoff water. Benchmarks for traffic-related pollutants in the runoff water discharged into groundwater and surface water are presented in Table 6. The decision regarding when and how to treat road runoff is made early in the planning of the road and has to be approved by the authorities. On the basis of previous measurements and monitoring programmes, the Austrian NRA has established a practice whereby road runoff is treated when the ADT reaches 15,000 vehicles/day.

[13] In this report the term 'treatment' is used when runoff water is collected and conveyed to a treatment facility and not passively drained over the road verge.

Table 6: Austrian benchmarks for some traffic-related pollutants in groundwater and surface water

Parameter	Benchmark groundwater	Benchmark surface water
Cadmium	4.5 µg/l	0.1 mg/l
Chrome	45 µg/l	0.5 mg/l
Copper	1800 µg/l	0.5 mg/l
Nickel	18 µg/l	0.5 mg/l
PAH (6)	0.09 µg/l	5 µg/l
Hydrocarbons total	100 µg/l	10 mg/l
Chloride	180 mg/l	-

Although guidelines on when to treat road runoff have been incorporated into Swiss road planning for several years now, there are no well-established benchmarks. A more comprehensive and detailed guideline has recently been developed. Now, ADT, number of heavy vehicles, and slope of the road are important criteria in the decision-making process (Guideline 18005 (ASTRA, 2013), see (Table 7). In practical terms, this has led to a benchmark of 14,000 vehicles/day for the treatment of runoff water in an appropriate treatment system. As in Norway, treatment is only considered for new-build road projects. Treatment of road runoff may occasionally be required in larger road maintenance projects (e.g. increase in the number of lanes or expansion of existing lanes).

Table 7: Key indicators for determining the efficiency of water treatment (operational phase) in Switzerland (ASTRA, 2013)

Project:	
Area: Treated road surface	
Amount of waste water Q_*	
Capacity of facility	
Recepient (without the treatment plant) - River: Q_{347} - Lake: surface F	

Indicators	
Benefits	
Reduction of emmission	
A	Traffic (logDTV)
B1	Intersection, junction, congestion
B2	Slope (in %)
B3	Heavy vehicles (in %)
C	Noise barriers on roads sides
	Total point A to C
D	Total efficiency
	Total point A to C multiplied with total efficiency
immission viewing	
E	Use of water, water protection area
F	Valuable, sensitive habitat
G	Size of the water body - River: discharge relationship V - Lake: Surface F, ha
H	By treating avoided water pollution, colmatation, siltation
I	Percolation of wastewater
	Total points benefits
Expeneses indicators	
J	Construction costs (costs incurred due to treatment) Number installations, electrical instrumentation Depreciation Operation, maintenance and disposal costs Annual costs annual costs per ha
K	
L1	Land area consumption for the system m^2
L2	Vulnerability of the claimed lands
L	Land consumption eff. (calc. automatically)
M1	Add of rainwater to the system
M2	Size of facility
	Total expenses points
	Quotient benefit / expenses

In order to ensure a proper level of pollution protection, the Irish NRA adopts best practice (i.e. sustainable urban drainage systems, SUDS[14]) for drainage systems on all new road projects. The decision whether to treat road runoff or not must be approved by the planning authorities. Currently there are no specific benchmarks (for example relating to ADT) on when to treat road runoff. However, there is on-going work to incorporate the Highways Agency Water Risk Assessment Tool (HAWRAT) system, a planning and decision-making tool developed by the Highways Agency of England (now Highways England). HAWRAT assesses the expected pollutant concentrations based on ADT, also taking into account the hydraulic characteristics of the recipient and runoff-specific threshold values (RSTs, see Table 8) derived from toxicity studies. Mitigation measures are included in the drainage design if the assessment tool identifies a particular risk to receiving watercourses. For a more detailed description of the HAWRAT, see Chapter 2.4.3.

Table 8: Runoff Specific Thresholds (RST) given in the HAWRAT (copied from Highways Agency (2009)

		Zinc (µg/l)		
		Hardness		
Threshold Name	**Copper (µg/l)**	**Low (<50mg $CaCO_3$/l)**	**Medium (50 to 200mg $CaCO_3$/l)**	**High (>200mg $CaCO_3$/l)**
RST 24 hour	21	60	92	385
RST 6 hour	42	120	184	770

In Italy, road runoff became an issue in the 1990s. In the early 2000s, there were more in-depth discussions regarding when and how to treat this type of water. This resulted in a guiding ADT benchmark of 15,000 vehicles/day for the treatment of road runoff. In specially protected and vulnerable areas, treatment may even be mandatory below 15,000 vehicles/day. Nevertheless, there are currently no official guidelines regarding when and how to manage runoff water. As in the other countries, the decision for or against treatment is made during the planning phase in an EMP, which must be approved by the authorities.

In Swedish road projects, the decision to include treatment systems to protect water bodies from pollution relies on a risk assessment conducted early in the planning phase. Dialogue with local authorities is important to ensure proper measures. The main factors considered are:

1 source (ADT and heavy vehicles including dangerous goods freight)
2 recipient (type, protection value, sensitivity)
3 source of contamination outside the road area
4 existing drainage system
5 cost and maintenance
6 motives and goals

There is currently no well-established benchmark regarding ADT. However, there is an acceptance that ADT < 2,000 vehicles/day does not justify the inclusion of treatment systems. In some

[14] The terms Structural and Non-structural Best Management Practice (BMP) are often used in other countries, e.g. United States. Structural BMPs are comparable with SUDS, while non-structural BMPs relate to source reduction such as road sweeping, public awareness, etc.

projects, local authorities may set benchmarks for some traffic-related pollutants. A monitoring programme is established to ensure that road runoff does not exceed the established benchmarks.

Tunnels

Tunnels constitute a special part of a road network. For obvious reasons, the tunnel environment is harsh, and dirt and dust are deposited and accumulate on the pavement, walls, ceiling, and technical equipment. This is why tunnels are washed on a regular basis. This tunnel wash water is normally highly polluted and potentially acutely toxic for aquatic organisms (e.g. Johansen, 2013). In comparison with ordinary road runoff, the pollutant concentrations in tunnel wash water are significantly higher at an otherwise similar level of traffic (Meland, 2010a). This is illustrated by data from Norway in Figure 10.

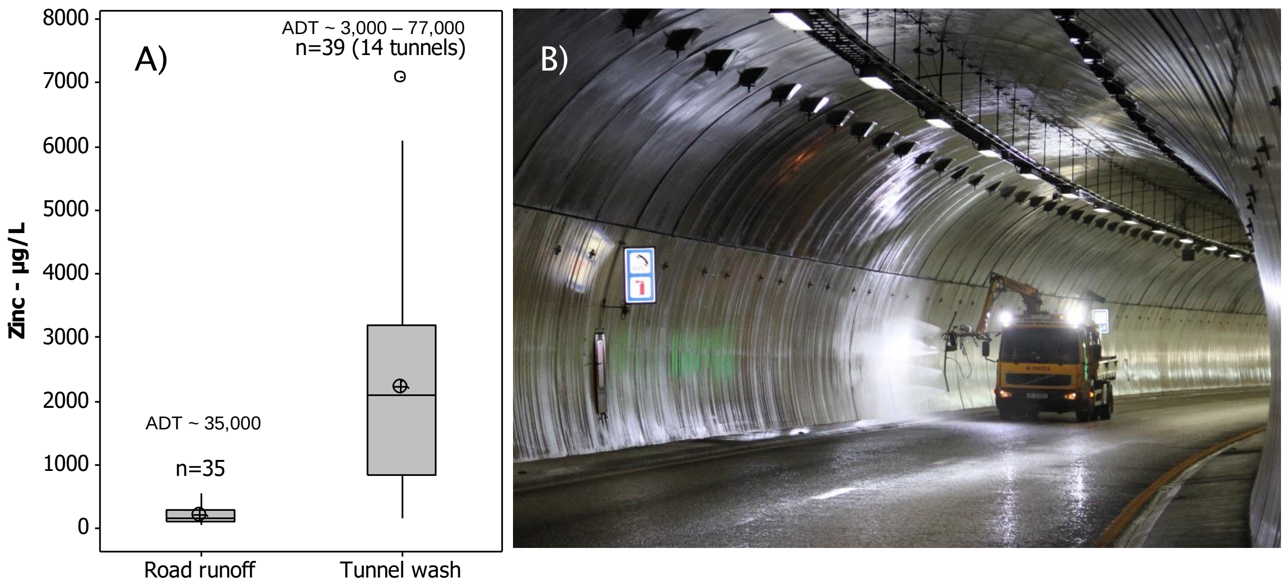


Figure 10: A) Box-plot showing Zn concentrations in road runoff episodes (E6 Skullerud, based on 35 episodes (Vollertsen et al., 2006; Åstebøl, 2004)) and tunnel wash water (tunnel wash sampling campaigns obtained from 14 tunnels (Unpublished data). Circle indicates an outlier and circles with cross indicate mean values. B) A washing event in a Norwegian tunnel (photo: Ellinor Hansen)

In Norway, which has more than 1,000 tunnels, tunnel wash water is in most cases discharged untreated[15]. However, in most of the bigger tunnels in and around cities built from the mid-1990s, tunnel wash water is discharged into sedimentation basins inside or ponds outside the tunnel. In new tunnelling projects, a permit from the regional environmental authorities is needed to discharge tunnel wash water. There appears to be an increasing awareness that tunnel wash water is a 'hot-spot' in terms of causing unacceptable damage to the aquatic environment, which is why most tunnels are now built with sedimentation basins.

[15] The tunnels are equipped with catch pits and sometimes oil interceptors, which are not viewed as treatment systems in the present report.

Similarly, tunnel wash water in Sweden is often discharged untreated even in bigger cities. However, increased awareness in recent years has changed the practice to include treatment systems in new tunnels. In some tunnels, the Swedish NRA has monitoring programmes to control pollution loadings. Such monitoring programmes are often used to represent a worst-case scenario regarding the pollutant loadings for an entire road network.

In contrast to Norway and Sweden, tunnel wash water in Switzerland and Austria is not allowed to be discharged untreated. In both countries, tunnel wash water is drained in a separate system and treated on site. In some cases, it is transported to an approved wastewater treatment plant (WTP).

Treatment of tunnel wash water in Italy is not mandatory. However, in new tunnels it is common practice to build a separate drainage system for tunnel wash water. In these tunnels, the wash water is collected and transported to an approved WTP. In older tunnels, the tunnel wash water is discharged untreated to the recipient.

Ireland has three tunnels. The wash water from two of them is collected and transported away to an approved WTP. In the third tunnel, the wash water is directly conveyed to an approved WTP through a bypass gate.

Bridges

Pollutants present in runoff from bridges are believed to be comparable with normal road runoff. However, bridges are technical structures with completely impervious areas with little or no flow attenuation or 'passive treatment' of the water (i.e. no trenches/ditches to retain and treat some of the runoff water). For this reason, runoff water is rapidly transported away from the bridge. The concentration of pollutants in bridge runoff water may therefore be higher than in normal road runoff at otherwise comparable ADT levels. However, there is currently little information about this. For most of the NRAs that contributed to the present report, runoff water from bridges follows the same requirements as for normal road runoff, and there are no specific criteria to decide whether to include any measures or not. The Swedish NRA states that runoff from bridges is an issue, and is therefore included in its risk assessment. Bridges crossing vulnerable recipients may therefore be equipped with drainage systems that convey the runoff water to treatment systems (Figure 11). The present review shows that the current practice among the countries represented in the TG is to discharge the runoff water directly into the water recipient or into the surrounding ground. However, in Switzerland and Italy the runoff water from bridges is sometimes drained into treatment facilities.

Figure 11: Gutters made out of stainless steel are mounted under a bridge across Lake Mälaren, the main drinking water source for the Stockholm region (photo: Swedish Transport Administration)

2.3.2 How contaminated runoff, including tunnel wash water, is treated

Roads

In Ireland, there has been a shift from conventional drainage systems such as petrol/oil interceptors towards vegetated systems within the SUDS framework (Figure 12 & Table 9). The policy is therefore to:

- use more sustainable drainage systems in order to mimic the natural catchment processes as closely as possible;
- use drainage techniques in series, incrementally reducing pollution, flow rates, and volumes of runoff to ensure water quality requirements are met;
- ensure that the need for large flow attenuation and flow control structures is reduced through the effective control of runoff at source;

and therefore ultimately to help meet the objectives of the WFD.

The benefits of such systems are, for example, that treatment is performed as close to source as possible and that the runoff is treated on its way to the recipient. The Irish NRA has several guidelines and standards describing the design of these systems.

Figure 12: Example of SUDS in Ireland. Combined wetland, sedimentation, and attenuation facilities (photo: Transport Infrastructure Ireland)

Table 9: Typical Sustainable Urban Drainage Systems (SUDS) used in Ireland

Management train suitability			
Treatment system	**Pre-treatment**	**Source control**	**Site control**
Filter drain		x	x
Infiltration trench		x	x
Soakaways		x	
Permeable pavement		x	x
Infiltration basin			x
Wetland			x
Retention pond			x
Swale		x	x
Filter strip	x	x	
Kerb and gully	x		

When treatment of road runoff is mandatory, the current practice in Austria is to build systems that combine sedimentation and filtration (Figure 13). The sedimentation step is constructed as a basin/pond either with or without permanent water. The infiltration step consists of an approximately equally sized basin with filter material (humus material) and a drainage layer. The treated water is discharged to the recipient (either groundwater or surface water). The filter layer is believed to operate over a 30-year perspective. However, in practice, the longevity of the filter capacity is still unknown as this approach only came into use in recent years. A common drawback of such systems is the clogging of the filters, which reduces performance. These treatment systems require adequate available space. An alternative, when space is limited, is to build technically advanced systems (Figure 13). Generally, these systems have the same function as the standard systems, but are much smaller, and commercial products are usually used for the filter material[16]. In contrast to the traditional systems, the technically advanced systems are designed to treat only the first flush of a storm event (15 min. of rainfall, one-year return period). The experience so far has been that compact systems are cheaper than traditional systems. Treatment performances have not yet been evaluated, but it is assumed that they will perform as well as the traditional systems. For this reason, the Austrian NRA believes that it will give preference to compact systems in future road projects. In addition, infiltration in swales and embankments may be accepted as a proper measure for road sections built before the 1980s.

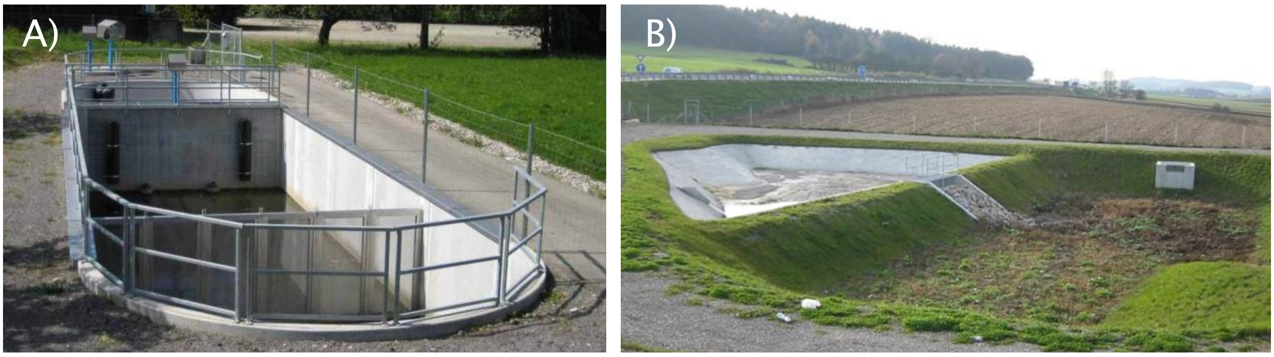


Figure 13: Treatment system in Austria. A) Compact system using commercially available filter material. B) Standard system combining sedimentation and infiltration (photo: ASFINAG)

In Switzerland, the environmental authorities do not consider sedimentation ponds alone to be an adequate measure for reducing pollution loadings. At present, there are only three approved methods for treating road runoff (various infiltration systems are displayed in Figure 14):

1 infiltration directly over the road verge (embankment),
2 collection and conveyance of runoff water to infiltration/filtration facilities (ditches, basins, etc.) with filter materials before discharge to ground water or surface water, and
3 discharge into the municipal drainage/sewage network (only in very special circumstances)

As stated in Chapter 2.3.1, treatment is considered mandatory when the ADT is approximately 14,000 vehicles/day. Road runoff is infiltrated and filtered through a substrate layer (good soil quality), which is considered to have a longevity of 50 years (similar to the practice in Austria). Problems with cracks in the filtering soil due to poor design/construction may occur.

[16] The Austrian NRA has not received any information from the manufacturer regarding the material content and the composition of the filters.

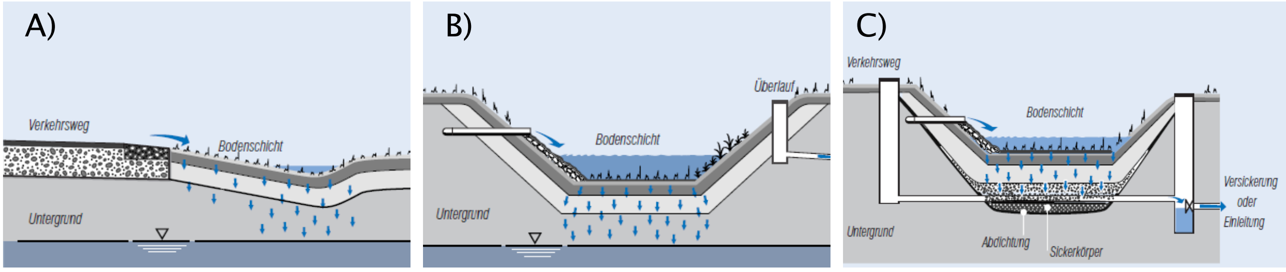


Figure 14: Conceptual drawings of treatment systems for road runoff in Switzerland. A) Infiltration over the road verge (embankment) to groundwater. B) Infiltration by means of ditches and hollows to groundwater. C) Infiltration and filtration before discharge to surface water or groundwater

Like Austria, Switzerland has started to use a more advanced treatment system. For example, a new central treatment plant along Highway A1 (Halenbrücke, crossing the River Aare) collects road runoff water from 18 km (275,000 m2) of roads. Water is conveyed to the treatment plant by three pumping units with small storing tanks (30–40 m3). The treatment plant has a huge storing capacity. Debris is removed before the sedimentation of particles. The runoff water is further treated by means of active carbon (anthracite) filters (Figure 15). The treatment plant is dimensioned to treat 88 per cent of all rain events. It is believed that such a huge treatment plant is more cost effective than building several minor plants. The performance will be evaluated by means of a monitoring programme.

Figure 15: The advanced technical treatment system at Halenbrücke, Switzerland. The plant was opened in 2015 and receives runoff from 18 km of roads with an ADT of approx. 90,000 vehicles/day. The treatment is based on storing, sedimentation, and one-step filtration with active carbon (anthracite). The capacity is 60 l/second. The system cost €4.8 million to build. A) At the basins. The insert shows filter material (the sand material on the left is used in another newly built treatment plant). B) Inside the treatment plant (photo: Sondre Meland)

On the basis of the first-flush concept, the Italian NRA has established a practice whereby small treatment tanks are used to retain water flow and pollutants within the first few minutes of a rain event (Figure 16). These tanks are also intended to be a proper measure against accidental spillage, for example from heavy vehicles. The tanks are normally made of concrete and are often situated underground. They have a volume of approximately 40 m^3 and are designed to retain particles and particle-associated pollutants as well as oil. As these units are rather small, it is important to have a proper maintenance programme, which includes the removal of trapped sediments. So far, the treatment performance of these systems has not been evaluated, but a monitoring programme has been launched. Initial results are expected to be available within the next few years.

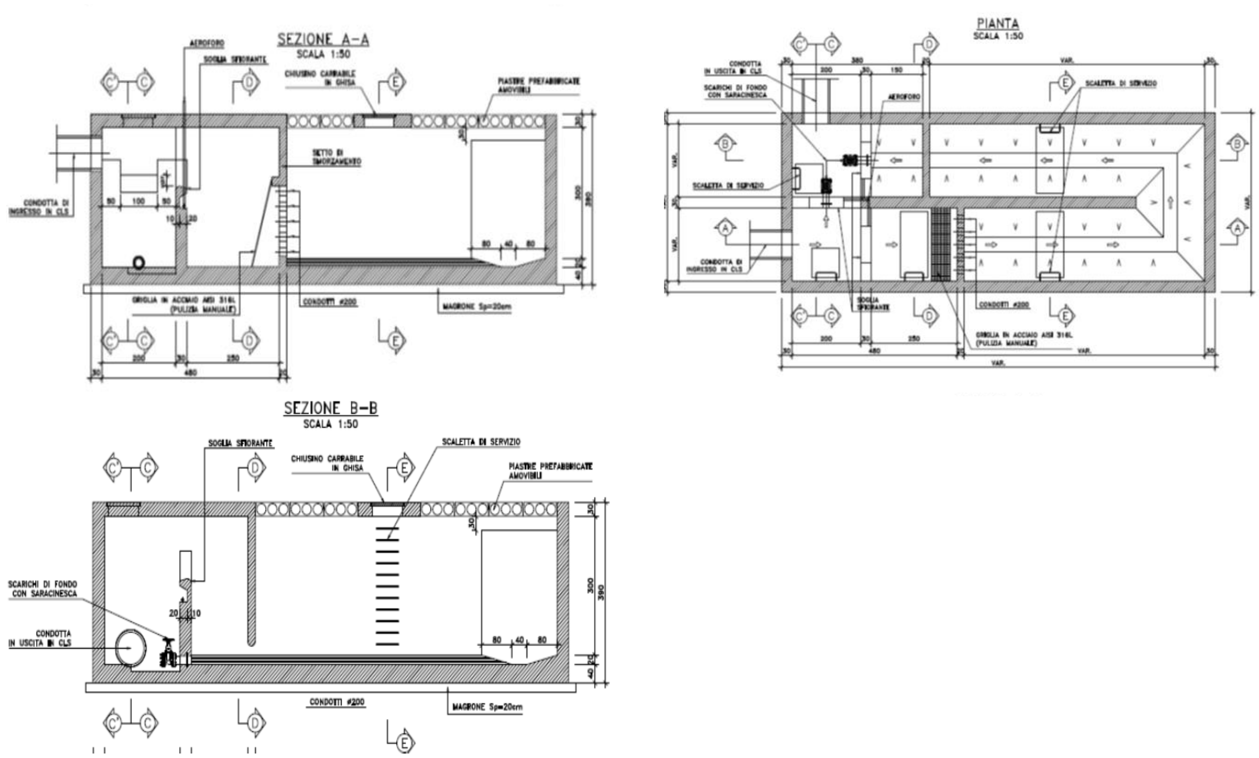


Figure 16: Technical drawing showing the section (left) and plan (right) of a concrete treatment tank used in Italy

In Sweden, road runoff is treated by infiltration in open ditches. In addition, there is a long tradition of using sedimentation ponds and/or wet infiltration ponds. The sedimentation pond is, however, by far the most frequently used measure on the Swedish road network. As mentioned above, sedimentation ponds may require large areas, and whenever space is limited (e.g. within the cities), sedimentation tanks with flocculation chemicals are used. In special cases, the Swedish NRA also uses silt curtains within the recipient as a way of trapping and retaining particles and particle-associated pollutants.

As in Sweden, by far the most frequently used treatment system in Norway is the sedimentation pond (Figure 17). Occasionally, wetlands, infiltration ponds, and ditches are used. The standard design of a sedimentation pond in Norway comprises a smaller pre-sedimentation pond (forebay) and a main pond, both of which contain permanent water. The inlet and the outlet are normally submerged to ensure proper function during wintertime when ice on the water can be an obstacle to water flow. The submerged outlet also functions as an oil separator. So far, filtration has not been included as a second treatment step together with sedimentation ponds. However, the Norwegian NRA is currently doing research on various filter materials to be used in ditches directly or as a second step in combination with sedimentation ponds. This would be comparable with the Austrian approach.

Figure 17: Example of a Norwegian sedimentation pond with a smaller pre-sedimentation pond (forebay, which can be seen in front of the band of vegetation crossing the pond) and a main pond (photo: Sondre Meland)

In Denmark, the use of ponds is considered best practice. Historically, the focus has been on mitigating peak flows rather than pollution control. This is because most of the land in Denmark is used for agriculture, and road runoff and storm water runoff may not be discharged uncontrolled into streams that are used, for example, for irrigation. For this reason, Denmark has a vast number of ponds. In fact, there is approximately one pond per km of road. In addition, the ponds are built large in order to store huge water volumes so that there is an ability to reduce the outflow down to a maximum 1–2 l/second per ha farmland. The focus on pollution control has gained more attention in recent years. There is now on-going research into combining sedimentation ponds and filtration in a treatment-train.

Several examples of treatment systems are presented in Appendix I.

Tunnels

As stated in Chapter 2.3.1, tunnel wash water in most Norwegian tunnels is not treated in any way. However, in those cases where treatment is mandatory, the practice has been to treat the wash water in sedimentation basins inside the tunnel or in sedimentation ponds outside. This is also the current practice for new tunnels. There are, however, indications that sedimentation alone is not sufficient as the sole treatment phase. For example, it has been proven that the use of detergents disturbs the sedimentation process for metals like Cu and Zn (Aasum, 2013). As a result, the Norwegian NRA plans to build a larger pilot treatment system, which includes steps such as sedimentation, flocculation, and filtration.

In larger tunnels situated in Sweden's major cities, the common practice is to use sedimentation basins in combination with chemical treatment such as flocculation and pH-adjustment. The preferred flocculent chemical is poly-aluminium chloride (PAX). However, research is currently being conducted to evaluate the performance of other flocculants as well. Sedimentation basins are often equipped with oil skimmers. Sensors are installed to control the functioning of the system. If an accident occurs in the tunnel, the outlet from the sedimentation basins can be closed from an operational control centre. The treatment systems are normally installed inside the tunnel (Figure 18). In smaller tunnels, the tunnel wash water is discharged to sedimentation ponds outside the tunnel.

Figure 18: Sedimentation basins inside the Södra Länken tunnel in Stockholm. The containers in the background are made out of stainless steel and contain the flocculent. An oil skimmer is visible just beneath the water surface (photo: Swedish Transport Administration)

In Austria, it is prohibited to discharge untreated tunnel wash water. The inrush of water from the surrounding rock and runoff water from tunnel road surface are drained in separate systems. The inrush water is monitored, and if pH levels are too high, the water is pH-adjusted with CO_2 before it is discharged to a surface recipient or infiltrated to groundwater. The tunnel road water is drained into a sensor chamber and a valve chamber where pH and oil-in-water are continuously monitored. The operating phase may be divided into three separate processes:

1. Normal: the tunnel road water is drained into an oil interceptor and then into a treatment system as shown in Figure 13.
2. Tunnel wash: the tunnel wash water is collected in a separate sedimentation basin. After sedimentation, the wash water is discharged into the public storm water system or treated on-site with a mobile tunnel wash water treatment unit (i.e. truck equipped with various treatment systems). The mobile treatment unit consists of a sand or bag filter, flocculation and finally an activated carbon filter. The cleaned water is discharged into the surface water recipient, while the sediment is disposed of by a waste collector.
3. Accidents: In case of an accident, the penstock to a separate small basin is opened and all others are closed. Any liquids and contaminated water are retained in the basin before it is collected and transported away by a waste collector.

As in Austria, it is prohibited in Switzerland to discharge untreated tunnel wash water. In addition, the separation of polluted water (i.e. road runoff, tunnel wash water, accidental spillage of hazardous liquids) and inrush water from the surrounding rock is mandatory. The current practice is to use sedimentation basins with a capacity of at least 150 m^3 of water. The treated wash water is normally disposed of at an approved WTP. In a few tunnels, however, the treated wash water is discharged to a recipient.

As already mentioned, Ireland has only three tunnels, and the wash water from two of the tunnels is collected and transported to a WTP. The third tunnel has a bypass gate, which is operated during the tunnel wash, which drains the wash water directly to a WTP.

In Italy, wash water is drained into sedimentation tanks before the treated water is transported away to a WTP. However, this practice is only valid for some tunnels (recently built or planned).

Bridges

Runoff from bridges may sometimes be collected and conveyed to a treatment system. This appears to be the practice in all CEDR countries.

Accidental spillage/ heavy vehicle accidents

Risk assessment regarding spillage caused by accidents involving heavy vehicles is performed in Ireland, Sweden, and Switzerland. The risk assessment is typically based on factors such as ADT, ADT of heavy vehicles, frequency of accidents, and the vulnerability of the recipient (e.g. drinking water). The Swedish and Swiss NRAs perform their risk assessments using a Geographic Information System model (GIS), while the Irish NRA has adopted the HAWRAT system. Based on the outcome of the risk assessment, measures are taken. In the case of accidental spillage, typical measures include the sealing of the road embankments and small treatment units.

In the other countries represented in the TG there is currently no available risk assessment tool for spillage caused by accidents involving heavy vehicles. The treatment systems along the roads are, however, capable of retaining unintended liquid spills. For example, liquids that are lighter than water (e.g. oil) are efficiently retained as the outlets are submerged. However, it should be noted that treatment systems are normally built to cope with ordinary pollution situations and not accidents. This is also the case for tunnels.

2.3.3 The operation, maintenance, and rehabilitation of water treatment systems

Although monitoring programmes are often required in Sweden, for example by the environmental authorities, there is currently no standardised programme (parameters, longevity of the programme, etc.). However, the Swedish NRA aims to standardise such programmes for future projects. Monitoring programmes are also commonly used in Austrian road projects to evaluate and control the performance of the treatment systems. A typical monitoring programme includes measurements of metals and organic parameters as displayed in Table 6 above. The sampling frequency varies from two times per year to once every fifth year. Over the last ten years, some of the monitoring programmes have been extended to include additional parameters, increased sampling effort, and even monitoring of the recipient which includes e.g. chlorides, on-line monitoring (pH and conductivity), and biota (e.g. macroinvertebrates). Monitoring programmes can also be required in Italy and Switzerland. Switzerland has in fact recently standardised the content of such programmes. In Norway and Ireland, monitoring programmes are not generally used. However, studies evaluating the measures have been conducted in both countries.

Standard technical guidelines describing how to operate and manage the various treatments are important in order to ensure good functioning and treatment performance. Such guidelines have been developed in Austria, Sweden, and Ireland. The Norwegian NRA is currently working on such guidelines.

2.3.4 Costs vs. utility of water treatment systems

The Irish NRA has estimated approximate unit costs for various treatment systems, their suitability, and benefits (Table 10). Switzerland has taken this a step further and developed a decision matrix (flow sheet) for selecting the most cost-effective (beneficial) system.

Table 10: Costs vs. utility of water treatment systems developed by the Irish NRA (copied from CIRIA, 2007)

			Management train suitability						Water quantity				Water quality								Environmental benefits		
Component	Cost €	Unit	Prevention	Conveyance	Pre-treatment	Source control	Site control	Regional control	Conveyance	Detention	Infiltration	Water harvesting	Sedimentation	Filtration	Adsorption	Biodegradation	Volatisation	Precipitation	Uptake by plants	Nitrification	Aesthetics	Amenity	Ecology
Filter drain	120 - 170	m^3 stored volume		x		x	x		x	x				x	x	x	x						
Infiltration trench	65 - 80	m^3 stored volume		x		x	x		x	x	x			x	x	x	x						
Soakaways	> 120	m^3 stored volume				x					x			x	x	x							
Permeable pavement	35 - 50	m^3 permeable surface	x			x	x			x	x	x	x	x	x	x	x				x	x	x
Infiltration basin	10 - 20	m^3 detention volume					x	x		x	x			x	x	x	x				x	x	x
Wetland	30 - 35	m^3 treatment volume		x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Retention Pond	20 - 30	m^3 treatment volume					x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Swale	10 - 20	m^2 swale area		x		x	x		x	x	x		x	x	x	x			x		x	x	x
Filter strip	2 - 5	m^2 filter strip area			x	x			x	x	x		x	x	x	x					x	x	x
Kerb and Gully	N/A	m length of pipe		x	x				x				x										

The typical cost of constructing an advanced treatment system in Austria is estimated to be €100,000–150,000, while the annual operating costs are approximately €5,000. In addition, changing filter material typically costs €20,000–40,000 (the expected lifetime is approximately 30 years). The Austrian NRA expects to use more technical treatment systems (more compact and with pre-fabricated filters) in the future. Although it expects a reduction in operating costs compared with the cost of the present systems, building costs are expected to be similar. In Switzerland, the new centralised treatment plant (A1 Halenbrücke) which cost €4.8 million is believed to be more cost efficient than having several more traditional smaller treatment facilities.

2.3.5 De-icing chemicals

For several decades, de-icing chemicals have been used in northern and central Europe to improve winter road conditions. Sodium chloride (NaCl, road salt) is the preferred chemical. However, environmental concerns have been raised and several studies have documented the negative chemical and biological impact of road salt on water bodies (e.g. Corsi et al., 2015; Jensen et al., 2014; Novotny and Stefan, 2012; Roe and Patterson, 2014). Although alternative chloride-based de-icing chemicals and organic de-icing chemicals do exist, none of them have proven to be better, less harmful, or more cost effective than NaCl.
Figure 19 shows the trend in road salt consumption in Norway and Sweden.
Figure 20 shows a lake impacted by road salt.
The Norwegian and Swedish NRAs aim to reduce their consumption of road salt. For example, the Norwegian NRA recently developed a flowchart method combined with maps (GIS-based system) to predict and forecast areas where road salt may have a negative impact on water bodies. Proper measures are then considered when the system classifies a water body as being 'at risk'. Although the aim is to reduce the amount of de-icing chemicals used, this may be hampered by changed weather conditions caused by climate change. For instance, the Swedish NRA stresses that climate change may in fact increase the need for de-icing chemicals because the frequency of periods when the temperature is around freezing point may increase, at least in northern countries.

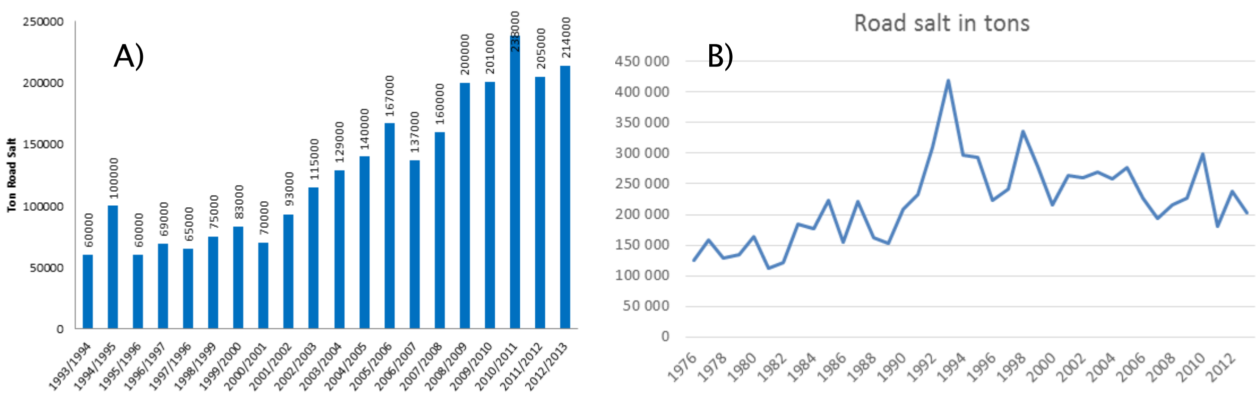


Figure 19: The amount of road salt (NaCl) used on the Norwegian (A) and Swedish (B) national road networks

There seems to be a growing awareness, also among the other countries represented in the TG, about the negative impact road salt may have on the aquatic environment. However, compared with Norway and Sweden there has not been a substantial effort to document this in the form of monitoring studies or other research. Compared with Norway and Sweden, annual salt usage in Ireland and Austria is lower. However, 50,000–100,000 tons/year may still be considered a significant amount of salt, which in fact may pose a threat to water bodies close to roads.

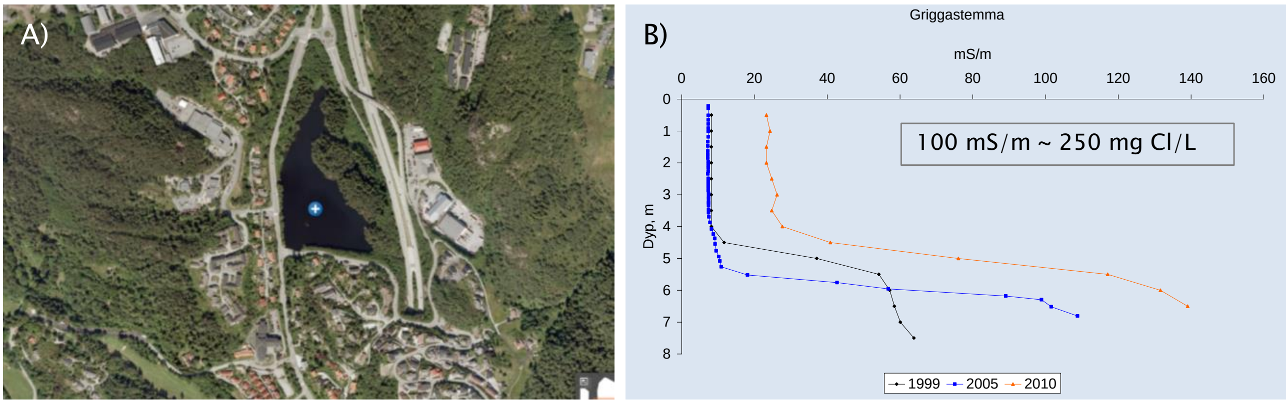


Figure 20: The Norwegian lake Griggastemma, adjacent to the E39 outside the city of Bergen, is severely affected by road salt. A) An aerial view of the lake and the surrounding roads. B) Vertical road salt concentrations measured in terms of conductivity showing chemical stratification from 4–5 m depth. Data obtained from the Norwegian Institute for Water Research (Bækken and Haugen, 2011)

2.4 Workshop: best practice in Germany, Poland, and the UK

A workshop with invited experts from Germany, Poland, and the UK was held in Stockholm in January 2015. Best practice regarding when and how contaminated runoff events are managed in these countries was presented and discussed. A brief summary of the practices in each of these countries is presented below.

2.4.1 Germany

Germany is a member of the EU, which means that the management of waters has to be in line with the WFD. Germany has a substantial road network, and there is currently little activity regarding the construction of new roads. However, the existing road network is constantly being maintained, improved, and upgraded. Management of road runoff is important and there are currently more than 1,000[17] treatment facilities along the German road network.

Drainage systems including treatment facilities are described in the technical guidelines 'Richtlinien für die Anlage von Strassen – Teil: Entwässerung (RAS-Ew)(FGSV, 2005)' and for areas of water protection in 'Richtlinien für bautechnische Massnahmen an Strassen in Wasserschutzgebieten (RiStWag) (FGSV, 2002)'. These guidelines cover the construction and operation phase respectively. However, for inter-urban roads, the REA-Ew requires infiltration of the road runoff if possible.

Similar to the other countries represented in the TG, permits are required for the discharge of runoff. The requirements in the German permits are normally set at local level. However, the current practice is that treatment of road runoff water is mandatory when the ADT exceeds 15,000 vehicles/day. Within the ADT band 2,000–15,000 vehicles/day, treatment is normally required depending on the recipient. Roads with an ADT of less than 2,000 vehicles/day do not normally require any treatment of road runoff. Infiltration of road runoff into the soil embankment is considered an adequate treatment method and is thus a preferred solution in Germany.

There is ongoing work at national level to use suspended particles[18] as an indicator for other road-related pollutants and to use that indicator as a benchmark for when to treat road runoff. This work was expected to be finalised during 2015. Currently, there is little emphasis on establishing benchmarks for other pollutants such as metals, hydrocarbons, PAHs. The reason for this is that a large fraction of these road-related pollutants are associated with particles. Benchmarks for Cl have occasionally been used to protect vulnerable recipients from road salt. For example, 10 mg/l Cl has been suggested as the benchmark for the protection of the endangered freshwater pearl mussel (*Margaritifera margaritifera*). Whenever treatment is mandatory, the current practice is to use sedimentation tanks either as a pre-treatment facility or as a full treatment facility. The former has a capacity of 15 l/(s*ha) and the latter 100 l/(s*ha). The treatment may be extended by a second infiltration step if required. Examples of treatment systems are shown in Figure 21.

[17] There is great uncertainty about the accuracy of this figure.
[18] Particles are measured as AFS_{63} which differ from the traditional parameter TSS. AFS_{63} is defined as kg suspended solids $_{\text{(fraction less than 63µm)}}$/a*ha, where a= annual, ha=hectare impervious area).

Figure 21: Example of German treatment facilities. A) Infiltration pond. B) Sedimentation tank followed by an infiltration step (soil filter) (photo: BASt/DEGES)

2.4.2 Poland

Poland became a member of the EU in 2004. The Polish NRA is thereby obliged to have a water management system that complies with the goals of the WFD. Poland has invested heavily in new roads; since 2007, more than 2,000 km of roads have been built. This major road construction scheme will continue in the years to come. As in other countries, the aim is to protect the aquatic environment from pollution. The Polish NRA conducts Environmental Risk Assessments (EIA) for a large majority of the road projects, which cover both a road's construction and operation phases. Based on a recent strategic EIA covering the years 2014–2023, the Polish NRA has registered 3,768 and 1,664 potential conflicts between existing and planned roads and surface waters respectively. The EIA must prove that the road project is not in conflict with the goals of the WFD, otherwise it may not be implemented. Permits are required before runoff may be discharged (the permits are usually given for a 10-year period). In those cases, where water treatment is mandatory, treatment systems such as oil interceptors, small sedimentation tanks, infiltration ponds, and wet ponds are built (Figure 22). Special emphasis has been placed on the discharge of particles (TSS) and hydrocarbons. Since 2014, the corresponding benchmarks have been 100 mg/l and 15 mg/l respectively. The EIA also states when measures are required. After the road is built, a monitoring programme is established to make sure that pollution concentrations do not exceed the benchmarks given in the permit. If they do, additional measures may be required. A typical monitoring programme includes the taking of measurements 12–18 months after the road is opened and periodically 3 to 5 years after that. The experience so far is that the established benchmarks for TSS and hydrocarbons are normally met.

Similar to the other countries represented in the TG, the use of de-icing chemicals may be high at certain periods. For the time being and since 2008, peak road salt consumption was registered in the winter season 2012/2013 where almost 600,000 tons were used on the Polish road network. Consequently, the Polish NRA has conducted some studies to investigate any negative biological impacts of road salt on the aquatic environment (e.g. stream-dwelling water plants and fish). The results obtained revealed no sign of biological stress.

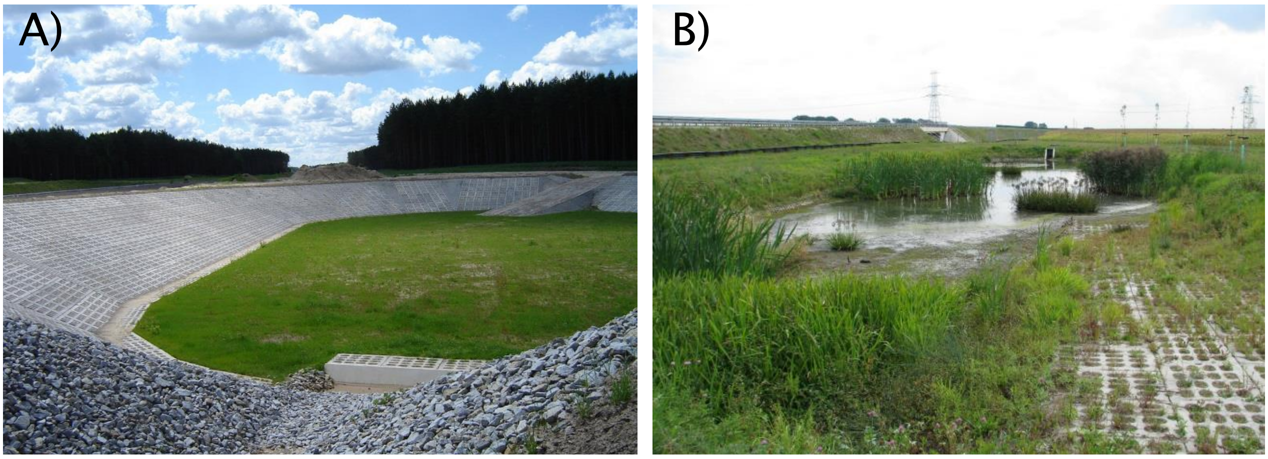


Figure 22: Example of infiltration ponds in Poland. A) S3 expressway Gorzów Wielkopolski – Miedzyrzecz, and B) S11 expressway Western bypass of Poznan (photo: General Directorate for National Roads and Motorways)

2.4.3 England

England is part of the UK and a member of the EU. The NRA is therefore obliged to apply a water management practice that complies with the goals of the WFD. There is a general right to discharge water from roads, but no right to pollute. Consequently, the English NRA has a responsibility to control pollution and to take appropriate measures to mitigate any effects on the aquatic environment. Today, there are approximately 900 ponds along the UK road network.

Environmental assessment regarding water pollution is described in the guideline 'Design Manual for Roads and Bridges' (DMRB) Volume 11 (Highways Agency, 2008a) and design guidance in Volume 4 (Highways Agency, 2006). The DMRB is mandatory for use on all road projects. Key features in Volume 11 are:

1) priority pollutants
2) ecology-based standards for receiving waters
3) Highways Agency Water Risk Assessment Tool (HAWRAT)

The design guidelines in Volume 4 provide guidance on the design, construction, and maintenance of drainage including SUDS.

To meet the demands of the WFD, the English NRA together with the Environment Agency ran a joint research and development (R&D) programme from 2002 to 2009. The programme had four main objectives:

1) to determine pollutants in highway runoff,
2) to examine the effects of soluble pollutants on the ecology of receiving waters,
3) to examine the effects of highway-derived sediment on ecology, and
4) to develop a practical risk assessment tool based on research findings.

Based on samples obtained from 340 rainfall events at 24 different sites, they were able to pinpoint that the metals Cu (total and dissolved), Zn (total and dissolved), and cadmium (Cd) together with total PAHs and two PAH compounds fluoranthene and pyrene were the most significant pollutants (Crabtree et al., 2009). Key factors that could describe a significant part of the observed variation in pollutant concentrations were traffic density, climate effects, and seasonality. However, it should be stressed that traffic used as the only explanatory variable to explain the observed variation was not statistically significant. This reflects the natural variation of pollutant concentrations in road runoff (i.e. variability within an event, between events at a specific site, and between sites). Based on the pinpointed pollutants, benchmarks were developed using toxicity tests including various aquatic organisms. By combining the resulting benchmarks with the concentrations observed in the sampled rainfall events, it was discovered that the benchmarks for Cu and Zn were exceeded several times, most of all in the higher traffic bands. Studies of sediments affected by highway-derived particles and pollutants revealed that metals and PAHs accumulated in biota and that this may have an impact at community level (i.e. not only on single species). Finally, the risk assessment tool HAWRAT was developed (see Figure 23 and Figure 24) on the basis of these results. The HAWRAT is therefore the only evidence-based risk assessment tool that takes into account biological and ecological considerations in combination with hydraulics and traffic characteristics. This is in contrast to all other risk assessment methods/tools used in Europe today, which normally rely on a fixed benchmark for traffic density. As this was a joint programme run by the NRA and the Environment Agency, the HAWRAT tool has become the accepted method for deciding when and how road runoff should be treated. The HAWRAT system has now been in use for several years and has proven to be a good tool for road planners and consultants. The HAWRAT tool is based on an Excel sheet interface and is available on the Internet free of charge www.haddms.co.uk.

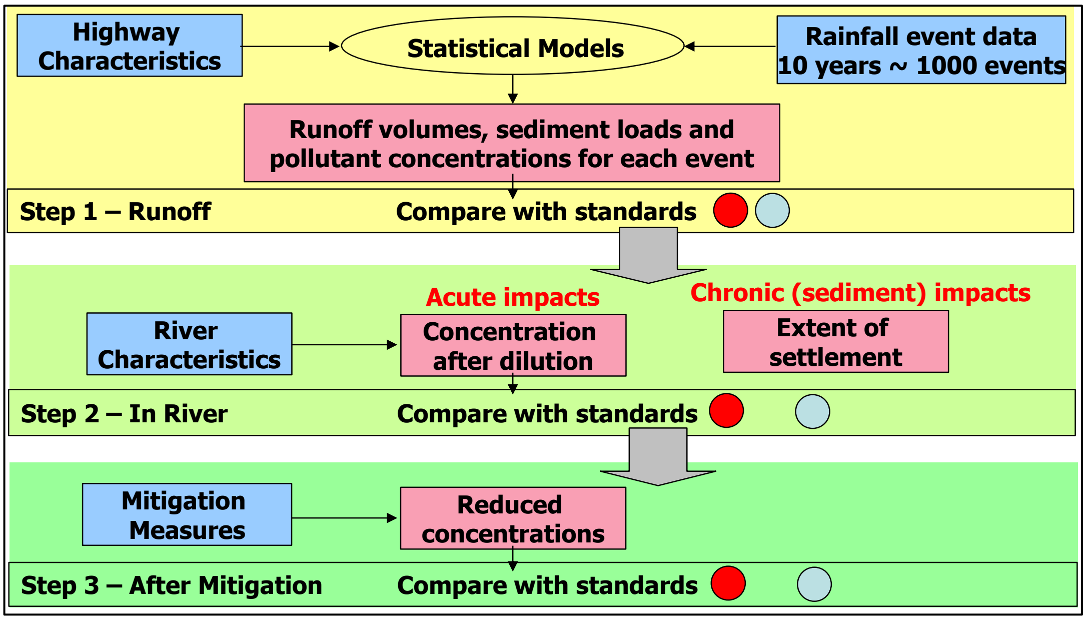


Figure 23: Flow chart of the Highways Agency Water Risk Assessment Tool (HAWRAT) (copied from Highways Agency, 2008b)

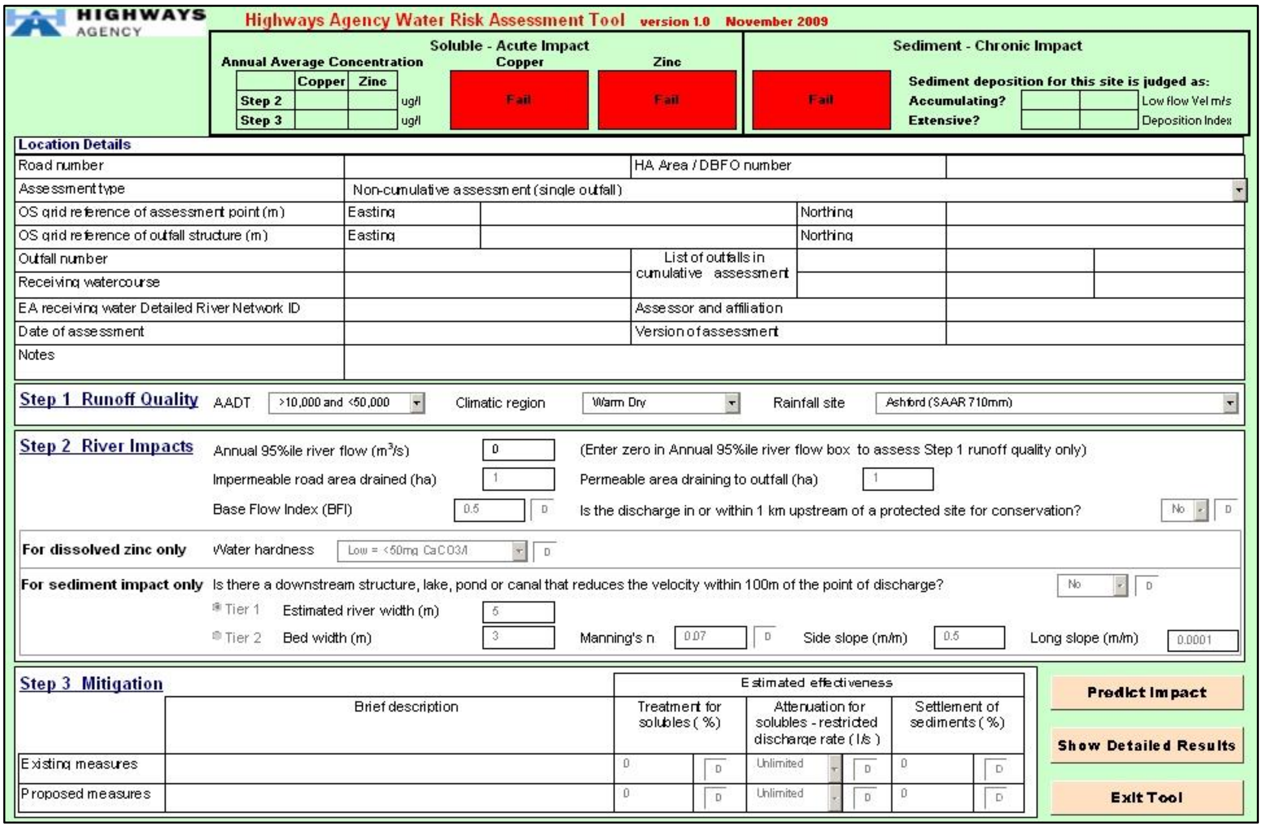


Figure 24: Screen shot of the Highways Agency Water Risk Assessment Tool (HAWRAT) user interface

It should also be emphasised that the English NRA has a forward programme of work for assessing and prioritising existing outfalls on its network that may pose a risk to the aquatic environment. The English NRA has a large number of outfalls including discharges to receiving water bodies and to groundwater (approximately 30,000) and so for practical reasons, it was unfeasible to use HAWRAT to undertake an initial assessment of risk. A GIS approach was therefore used to generate a baseline risk score for each outfall using criteria similar to those used by the HAWRAT as an initial screening process. On identification of a high baseline risk, HAWRAT is then used as the method of 'validating' the risk before committing capital funding to mitigating a location. As part of the UK Roads Investment Strategy, a clear commitment has been made to delivering enhancements to the road network that go beyond business as usual, and a ring fenced Environment Designated Fund of £300m has been established to assist with this. Delivering improvements to water quality from road discharges has been identified as a core activity against which funds can be used.

3 Future research needs

This chapter gives a brief overview of knowledge gaps and research needs identified by the TG members through individual work, two meetings conducted in 2015 and 2016, and the workshop in Stockholm in January 2015. The identified research needs are briefly outlined in Table 11. For a full description of the research topics and specific project proposals, see Appendix II.

Table 11: Proposed future research needs. The table gives a brief overview of the various research topics and subtopics. All the proposals are of both national and transnational interest. The proposals recommended for prioritisation by TG I5 (Water Quality) are marked in bold/underlined. For an extended version of this table, see Appendix II

Research topic	No.	Subtopic
Risk assessment tools for deciding when road runoff should be treated	**1**	Establish models that predict the pollution concentrations and loadings in road runoff
	2	Establish methods for assessing the water bodies' vulnerability to polluted runoff
The performance and cost-benefit of treatment systems for polluted runoff including tunnel wash water	**3**	Increase knowledge of the treatment performance and cost-benefit of existing treatment systems (e.g. SUDS) and more recently built technically advanced treatment systems
	4	The treatment performance and cost-benefit of commercially available technical filter materials compared with soil filters
	5	The long-term performance of soil filters in treatment facilities. Efficiency versus investment and operational costs
	6	Alternative and innovative treatment methods for tunnel wash water
	7	Treatment methods that reduce the impact of high levels of chlorides
The performance and cost-benefit of treatment systems for runoff during road construction including tunnelling water	8	Denitrification of water from construction sites contaminated with undetonated explosives
	9	Treatment methods for runoff water during construction
	10	Recycled material such as concrete and asphalt and other waste materials in the construction of new roads may leach hazardous substances to the aquatic environment. The risk of leaching may be reduced by using safety measures, e.g. technical safeguard material (TSM).
The environmental impacts of de-icing chemicals	**11**	Chemical impacts and stratification in lakes and streams due to the use of road salt (NaCl)
	12	Chemical impacts on ground and surface water bodies due to the use of alternative de-icing chemicals
	13	Cost-benefit analyses: comparisons of road salt and alternative de-icing chemicals and other physical and mechanical measures.
New and emerging chemicals	14	New technology and materials in the car industry will most likely change the content and composition of pollutants in road runoff.
	15	New technology and materials in the construction industry will most likely change the content and composition of pollutants in road runoff.
	16	The screening of new and emerging chemicals in road runoff
	17	Micro-plastic in the environment has attracted a lot of attention and is now considered a problem worldwide. Tyres are believed to be a significant source of plastic in the environment, but are there other sources from roads and traffic?
Climate change and water quality	18	Climate change, with increased and intense precipitation, affects road runoff in terms of road runoff volumes (flooding) and pollution loadings/concentrations.
Meta studies	19	Transnational coordination of existing research results

Six research topics were identified during the present work, covering risk assessment (1), the performance and cost-benefit of treatment systems for runoff both in the construction and operation phase of the road network (2 and 3), the environmental impacts of de-icing chemicals (4), new and emerging chemicals (5), and climate change and water quality (6). Within these main topics, 18 proposals for future research needs were identified (subtopics). In addition, one proposal was to perform meta-studies, which could cover most of the topics presented in the present report.

The present list of topics would be a solid foundation for further refinement of future research. Although all the topics listed are of transnational interest, they are not necessarily of equal importance to all CEDR countries. TG I5 (Water Quality) suggests that research relating to risk assessment (proposals 1 and 2), the performance and cost-benefit of treatment systems (proposals 3–6), and the environmental impact of de-icing chemicals (proposals 11–13) should be prioritised. Research into these topics could be conducted at either national or transnational level. The latter implies conducting research funded by CEDR, EU Horizon 2020, NordFoU[19], or other similar bodies and programmes.

[19] The Nordic NRAs are united in their efforts for strategic research cooperation with the purpose of coordinating and financing common research needs (www.nordfou.org)

4 Summary and ways forward

4.1.1 The planning and construction phase

The present SoAR shows that all countries represented in the TG need to address environmental issues such as water quality when planning, building, and operating the road network. During the construction phase, there is a common approach among the countries represented in the TG to conduct EIAs or similar assessments that describe how to prevent pollution and protect water bodies against pollution. Some countries have internal guidance documents, but not all. In addition, all countries represented in the TG seem to make the building contractor accountable for adopting proper measures to meet environmental requirements, e.g. various pollutants and their corresponding benchmarks. The pollutants and their corresponding benchmarks are not standardised, neither between countries nor within countries, but are more or less site specific. Various measures are used to avoid pollution; low-cost systems are preferred. However, there appears to be little data or experience regarding how these treatments systems perform on site. The environmental consequences related to road building projects are also poorly described in the scientific literature.

4.1.2 Operational phase: when to treat

In the operational phase, the decision to treat runoff water or not is more or less based on traffic density measured as ADT. The ADT benchmarks in the different countries represented in the TG lie within the range of 10,000–15,000 vehicles/day. In certain cases, such as protected water areas or very vulnerable recipients, the ADT benchmarks may be lowered. In this respect, it should be stressed that there are no well-established criteria for defining what a vulnerable recipient is in terms of road runoff pollution. However, Portuguese and Slovenian researchers (Brenčič et al., 2012) have developed a methodology for defining water bodies that are vulnerable to road pollution. However, that method (flow-chart methodology) only takes into account the physical and hydro-morphological properties of the water body and not the physico-chemical (e.g. bioavailability) and biological properties (e.g. pollution-sensitive species and red-list species). The authors of the present report do not know whether this methodology is implemented and used by the NRAs in the two countries.

From a scientific point of view, the reasons for the established ADT benchmarks are not well founded. For example, the concentrations and mass fluxes of pollutants in road runoff are likely to be affected by many factors such as weather and climate conditions, traffic parameters such as ADT, the relationship between light and heavy vehicles, the amount of studded tyres during winter (Nordic countries), driving speed, characteristics of the road such as age, mineralogy in the asphalt type, and maintenance such as road sweeping, de-icing etc. (Meland, 2010a). Consequently, the correlation between ADT and pollution concentrations measured in road runoff has proven to be rather weak, and the established practice of using ADT is probably more of a 'precautionary principle'. We believe that this may frequently result in an over-provision of measures to mitigate perceived negative impacts and a misdirection of the limited resources available for the protection of water bodies (under-provision may also occur but probably to a lesser extent). There is one exception to this practice and that is the HAWRAT system developed and used in the UK. HAWRAT is based on data from a larger research programme conducted together with the Environment Agency. This collaboration between the Highways Agency and Environment Agency appears to be unique in Europe. Although there are no exact references to road runoff in the WFD, the HAWRAT system may be more in compliance with the WFD in terms of mitigating chemical impacts compared with practice in other countries. Moreover, according to the English NRA, an important output from this joint project is that EIAs have become more predictable for road planners in terms of incorporating the WFD into their runoff water management. Despite a common understanding and agreement, the HAWRAT model has some shortcomings relating to the weak correlation between traffic and climate characteristics and pollution concentrations as well as uncertainties relating to the toxicity-derived benchmarks used in the model (e.g. choice of biological endpoints[20] and their sensitivity to detect sub-lethal effects). The uncertainties may lead to wrong decisions regarding whether to treat or not. However, we believe that it is significantly more accurate than using a fixed ADT. Consequently, as a system and a decision tool, the HAWRAT model is appealing and can be further developed and improved as new scientific data becomes available. The user-friendliness of such tools is important and should be emphasised.

An important aspect of highway runoff, but one that is rarely described in the relevant literature, is runoff from tunnel washing. The concentrations of most pollutants appear to be significantly higher in tunnel wash water compared to what is generally found in road runoff. In addition, the use of detergents may be both directly toxic in itself and indirectly toxic by increasing the bioavailability of other pollutants. In addition, the detergents seem to impair the treatment performance, which may result in the remobilisation of pollutants. Tunnel wash water may thus be considered a hot-spot that should not be discharged untreated to water bodies. At present, the management of tunnel wash water varies from country to country. Of greatest concern in this respect is the fact that the countries with the highest number of tunnels do not consider treatment to be mandatory. Finally, road salt is commonly used to increase traffic safety. However, as documented by many, the high road salt consumption is having a detrimental impact on the aquatic environment, which is of serious concern.

4.1.3 Operational phase: how to treat

It is generally accepted that road runoff may pose a pollution threat to water bodies, and there has been a shift from conventional drainage systems towards more blue-green solutions, which are also known as SUDS or Structural BMPs. Several systems are considered SUDS. It would appear that the preferred treatment system varies from country to country. In addition, factors such as available space and maintenance costs affect the choice of system. Some utilise ponds and basins/tanks, while others use either infiltration or ponds and basins together with infiltration. For example, the use of ponds as a sole measure is not considered acceptable in Switzerland, while in Italy the strategy is to treat the initial part of a storm event (i.e. the first flush) in small tanks. The benefit of combining ponds/basins and infiltration is that particle-associated pollutants are treated by sedimentation, and soluble pollutants by infiltration and sorption processes. However, as mentioned above, space may sometimes be a limiting factor, especially in more urban areas. However, there is an on-going effort in Austria to develop technical systems that require less space, i.e. smaller units that treat the first flush by sedimentation and filtration. In contrast, the Swiss NRA has built a larger treatment plant that receives runoff water from a greater road area, which is believed to be more cost efficient than building several smaller treatment facilities. It

[20] Biological endpoint: the toxic effect at a selected endpoint or criteria for effect, i.e. death or another adverse effect on the organism.

should be emphasised that no one overall treatment is superior to all others. The best available technology (BAT) may instead be considered site specific. Despite this, countries such as Switzerland, Austria, and Germany seem to have an extended toolbox of treatment methods compared to other countries such as the Nordic countries and Ireland. This report also indicates that operation and maintenance of the treatment facilities are often neglected, leading to either poor treatment performance or total breakdown of the facility. This increases the risk of harm being caused to the aquatic environment and potentially raises the costs related to water management.

Although SUDS and Structural BMPs have been in use for some decades, there are still uncertainties regarding their performance (especially organic micropollutants) and functionality. Recently, SUDS such as wetland and ponds have attracted much attention for their provision of benefits in addition to pollution and water volume control. Such benefits, also known as ecosystem services[21], include greenhouse gas regulation, air quality, climate, recreation, education and biodiversity. According to Moore and Hunt (2012), these benefits are often acknowledged but rarely quantified. This statement appears to be coherent with current NRA practice. It is in fact documented that SUDS (i.e. wetlands and ponds) may enhance biodiversity at local and regional level. Scientific interest in these issues is increasing, and TG I5 (Water Quality) believes that more information will become available in years to come (see 'The ecology and biodiversity of urban ponds' by Hassall (2014) for the latest review).

Finally, the cost-benefits related to building, operating, and maintaining these systems are only marginally addressed by NRAs in the present working group, and research is therefore warranted. For instance, the use of Life Cycle Assessments (LCA), Life Cycle Cost Analysis (LCCA) and Ecosystem Services Assessments (ESA) could, in this respect, be an important supplement to traditional cost-benefit analysis in planning, designing, and managing SUDS and BMPs. This would improve the decision-making process regarding water management, i.e. when and how road runoff should be treated.

4.1.4 The EU Water Framework Directive's role in NRA water management

The present work shows that the NRAs' involvement and participation in the WFD's RBMPs vary substantially from a high level of involvement to no involvement at all. However, as stated in Chapter 3.1.1, all countries need to address environmental issues such as water quality when planning, building, and operating the road network in order to meet the requirements of the environmental authorities and regulations such as the WFD. It is important to remember that the overarching goal of achieving 'good ecological and chemical status' as stated in the WFD relates generally to the protection of water bodies without making a specific reference to non-point source pollution such as road runoff (Yannopoulos et al., 2013a) and storm water runoff (Yannopoulos et al., 2013b). Although not part of the present report, the physical impacts of roads, such as barriers to fish migration or impairments of habitats, must also be accounted for. Thus, it is not possible to conclude whether current NRA water management practice complies with the WFD or not. Bearing

[21] The term 'ecosystem services' refers to any of the benefits that ecosystems, both natural and semi-natural (e.g. SUDS and BMPs) provide to people. These services include food and raw material provision, air and water purification, biodiversity maintenance, and aesthetic and other cultural benefits. More information may be found in Moore TLC, Hunt WF. Ecosystem service provision by stormwater wetlands and ponds - A means for evaluation? Water Research 2012; 46: 6811–6823.

this in mind, the inclusion of measures in both the construction and operational phases is very much in accordance with the WFD. For example, the use of BAT is often considered a pragmatic approach to solving a problem (European Commission, 2013; Hvitved-Jacobsen et al., 2010). However, chlorides from road salt are highly mobile and will not be retained or treated by any common treatment method. Consequently, the impairment of water bodies due to road salt and other de-icing chemicals may in fact be in violation of the WFD[22]. In addition, there is still a lack of knowledge about the chemical and biological impacts of roads other than the use of road salt on them, especially during construction, and of the long-term consequences of the operational phase. In addition, there is a certain discrepancy between the various countries regarding their management of runoff, both in terms of when treatment measures are needed and, if needed, which treatment methods are applied.

The first cycle of RBMPs has recently been completed and revealed that huge effort is still needed if the WFD's main goal of achieving 'good status' for all European waters is to be reached. How many roads and how much traffic contribute to the perturbation of European waters is still unclear. For this reason, the engagement of NRAs, together with other sectors and interested parties in the WFD and the up-coming RBMPs of the 2021 and 2027 cycles may be important in terms of achieving the goals of the WFD. We believe that increased engagement from the NRAs will contribute to greener transportation, thereby reducing its negative impact on the environment and key assets like water and ecosystems. This would be in line with the present European transport policy.

4.1.5 Possible ways forward

Generally, we recommend that the NRAs' engagement in the WFD and the accompanying RBMPs increases and that the NRAs work with environment agencies at national or European level to develop a proportionate design response to the risks presented to water quality by road runoff. This proportionate design response should not be confined to proposed road developments but should cover the entire existing national road networks. Moreover, a programme of retrofitting treatment facilities should be developed, starting with the worst offenders, which are probably tunnel wash water and road salt. Five suggestions on ways forwards are presented to meet this:

1. Together with environmental agencies at national or European level, the NRAs should initiate and develop a common understanding on when to treat road runoff. The goal must be to move from a fixed ADT benchmark towards a more evidence-based/science-based decision-making approach, which would include traffic and road characteristics combined with knowledge about the pollutants and their presence, behaviour, and fate in the aquatic environment. For example, knowledge about emerging chemicals - especially those believed to be persistent and toxic at low levels - is needed (e.g. persistent organic pollutants, POPs). In addition, it is important to assess the vulnerability of the water body to pollutants in runoff, taking into account hydro-morphological characteristics, water quality characteristics, and biological considerations. The work must take into account the goals and requirements of the WFD and also the fact that the pollution pattern (pollutants, concentrations, duration, etc.)

[22] Chloride is presently not on the EU's list of priority substances. However, it is regulated in countries such as the USA and Canada, where road salt has become a major environmental concern in recent years.

vary from the construction to the operation phase (i.e. a recipient's vulnerability may be different in the two phases).

a The development of the HAWRAT system is evidence of how the engagement and endorsement of the Environment Agency and the English NRA allowed for a common understanding and solutions on how to manage road runoff. The HAWRAT system could be a good starting point for other NRAs, but it should be stressed that any assessment tool should be up-dated as new knowledge is acquired and developed in a user-friendly manner.

2 NRAs should improve water management by developing guidelines that cover both the construction and operation phases. In the construction phase in particular, there is room for improvement. For example, NRAs should play a more active role in deciding which measures and systems should be adopted instead of just relying on the contractors' experience. TG I5 (Water Quality) also believes that the NRAs should emphasise the importance of having good follow-up routines during implementation of the various measures and that their performance and effectiveness should be evaluated and made accessible to others.

a Although treatment methods for road runoff in the operation phase vary from country to country, their performance (e.g. removal rates) is widely described in the relevant literature. However, there are still debates about the methods that are most suitable for the protection of water bodies. NRAs should therefore initiate, together with the environmental agencies, programmes and/or research to identify and develop a proportionate design response to the risk presented to water quality by road runoff events. In this respect, retrofitting existing treatment facilities and prioritising the worst sources of pollution is important. The proportionate design response should be holistic in the sense that the fate and behaviour of both classical traffic-related pollutants and new and emerging chemicals including POPs must be considered. In addition, the evaluation of their performance should include chemical speciation that emphasises bioavailability of the pollutants and biological endpoints including lethal and sub-lethal effects (e.g. biomarkers[23]). Finally, NRAs should emphasise the importance of using cost-benefit analyses or similar analyses in the decision-making process.

3 NRAs should challenge the car manufacturing industry and related industries (e.g. tyre manufacturers) to use less hazardous substances in production, as vehicles are one of the most significant sources of pollutants present in road runoff. Stopping the pollution at source is generally much cheaper and sustainable than taking pollution-reduction measures on the roads. CEDR should therefore initiate discussions with industry with the aim of reducing the pollution signature from the vehicle. This will also be in line with the 'polluter pays' principle. In addition, source reduction should also be emphasised within the NRAs themselves. Special focus should be put on replacing hazardous substances with more environmentally friendly alternatives in both the construction and operation phases.

[23] The term 'biomarker' may refer to all biological indicators (i.e. biochemical, physiological, histological, morphological, behavioural etc.) measured inside an organism or its products. See e.g. van der Oost R, Beyer J, Vermeulen NPE. Fish bioaccumulation and biomarkers in environmental risk assessment: a review. Environmental Toxicology and Pharmacology 2003; 13: 57–149.

4 NRAs should initiate and conduct research in order to be able to improve water management in terms of meeting the requirements of the WFD and other relevant regulations/directives. In addition, research will enable the NRAs to meet society's expectations that the environmental impact of roads must be reduced as much as possible in order to preserve, protect, and improve water bodies. In this report, TG I5 (Water Quality) presents future research needs and concludes that research within the areas of 'risk assessment', 'performance and cost-benefit of treatment systems for runoff', and 'the environmental impact of de-icing chemicals' is most important. This could be a good basis for a CEDR research call within the 'environment' theme in 2016. However, both the NRAs and CEDR should initiate research covering all aspects related to polluted runoff during both construction and operation of the road network. CEDR should also establish dialogue with the EU with the aim of including the above-mentioned topics in Horizon 2020.

5 The NRAs and CEDR should continue the work started in SP3 in SP4, as water management will continue to be an important issue both at national and European level.

All the 'ways forward' listed here may be conducted at national and/or European level. If the NRAs decide to act on these ways forward at European level, CEDR should be responsible for initiating collaboration with the European Environment Agency. TG I5 (Water Quality) believes that the suggested ways forward would significantly improve decision-making in terms of when and how road runoff should be treated. It does not imply that the NRAs would reduce the costs of water management, but it would ensure that money is used better in terms of *where* and *when* it is spent. This would help make transportation greener, thereby reducing its negative impact on the environment and key assets like water and ecosystems. This would be in line with the present European transport policy.

5 References

Aasum J-H. Effekter av vaskemiddel (TK601) på mobilitet av metaller ved sedimentering av tunnelvaskevann fra Nordbytunnelen (E6), Ås kommune, Akershus: et laboratorieforsøk. Universitetet for Miljø- og biovitenskap, Ås, 2013, pp. 102.

Angermeier PL, Wheeler AP, Rosenberger AE. A conceptual framework for assessing impacts of roads on aquatic biota. Fisheries 2004; 29: 19-29.

ASTRA. Richtlinie. Strassenabwasserbehandlung an Nationalstrassen. 18005. ASTRA Switzerland, 2013, pp. 90.

Brenčič M, Barbosa A, Leitão T, Rot M. Identification of water bodies sensitive to pollution from road runoff. A new methodology based on the practices of Slovenia and Portugal. In: Rauch S, Morrison GM, editors. Urban Environment. 19. Springer Netherlands, 2012, pp. 225-235.

Bækken T, Haugen TO. Road salt and heavy metals in lakes (In Norwegian). NPRA-report. 50. Norwegian Public Roads Administration, Oslo, 2011, pp. 63.

CIRIA. Control of water pollution from construction sites. Guidance for consultants and contractors (C532). C532. CIRIA 2001, pp. 256.

CIRIA. Control of water pollution from linear construction projects. Technical guidance (C648). C532. CIRIA 2006, pp. 234.

CIRIA. The SuDS Manual (C697). C697. CIRIA 2007.

Coffin AW. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography 2007; 15: 396-406.

Corsi SR, De Cicco LA, Lutz MA, Hirsch RM. River chloride trends in snow-affected urban watersheds: increasing concentrations outpace urban growth rate and are common among all seasons. Science of The Total Environment 2015; 508: 488-497.

Crabtree B, Dempsey P, Johnson I, Whitehead M. The development of an ecological approach to manage the pollution risk from highway runoff. Water Science and Technology 2009; 59: 549-555.

EEA. The EU Water Framework Directive. European Comission, Directorate-General for the Environment, 2014, pp. 4.

Egger M. Strategic Plan 3 2013-2017. Conference of European Directors of Roads (CEDR), Paris, 2013, pp. 73.

European Comission. Water is for life: How the Water Framework Directive helps safeguard Europe's resources. EC, Luxembourg, 2010, pp. 25.

European Comission. White paper on transport: Roadmap to single European transport area - Towards a competitive and resource-eficient transport system. EC, Luxembourg, 2011, pp. 28.

European Comission. Report from the Commision to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC). River Basin Management Plans. EC, Luxembourg, 2012a, pp. 14.

European Comission. Road Transport - A change of gear. EC, Luxembourg, 2012b, pp. 16.

European Comission. A Water Blueprint for Europe. EC, Luxembourg, 2013, pp. 28.

FGSV. Richtlinien für bautechnische Maßnahmen an Straßen in Wasserschutzgebieten" (RiStWag). Forschungsgesellschaft für Strassen- und Verkehrswesen 2002.

FGSV. Richtlinien für die Anlage von Straßen. Teil: Entwässerung (RAS-Ew). FGSV 539. Forschungsgesellschaft für Strassen- und Verkehrswesen 2005.

Hassall C. The ecology and biodiversity of urban ponds. Wiley Interdisciplinary Reviews: Water 2014; 1: 187-206.

Highways Agency. Design Manual for Roads and Bridges (DMRB). Geotechnics and Drainage. Volume 4, 2006.

Highways Agency. Design Manual for Roads and Bridges (DMRB). Environmental Assessment. Volume 11, 2008a.

Highways Agency. Improved determination of pollutants in highway runoff phase 2. Final Report. Highways Agency, 2008b, pp. 102.

Highways Agency. Design Manual for Roads and Bridges. Volume 11 Environmental Assessment. No. 11. UK Highways Agency, London, 2009, pp. 129.

Hindar A, Nordstrom DK. Effects and quantification of acid runoff from sulfide-bearing rock deposited during construction of Highway E18, Norway. Applied Geochemistry 2014; 62: 150-163.

Hvitved-Jacobsen T, Vollertsen J, Haaning Nielsen A. Urban and Highway Stormwater Pollution. Concepts and Engineering. Hoboken: CRC Press, 2010.

Håøya A-O, Storhaug R. Guidlines for treatment of water from roads and construction works. A comparison of methods and practice in 12 countries (In Norwegian, an English translation is available upon request). Nr. 195. Norwegian Public Roads Administration, Oslo, 2013, pp. 100.

Jensen TC, Meland S, Schartau AK, Walseng B. Does road salting confound the recovery of the microcrustacean community in an acidified lake? Science of The Total Environment 2014; 478: 36-47.

Johansen SL. Element accumulation and levels of four biomarkers in common frog (Rana temporaria) tadpoles in two sedimentation ponds and naturally occurring pond. MSc-thesis. Norwegian University of Life Sciences, Ås, 2013, pp. 80.

Maltby L, Forrow DM, Boxall ABA, Calow P, Betton CI. The effects of motorway runoff on fresh-water ecosystems. 1. field-study. Environmental Toxicology and Chemistry 1995; 14: 1079-1092.

Meland S. Ecotoxicological Effects of Highway and Tunnel Wash Water Runoff. PhD-thesis 2010:25. Norwegian University of Life Sciences, Ås, 2010a, pp. 86.

Meland S. Ecotoxicological Effects of Highway and Tunnel Wash Water Runoff. 2010:25. PhD-thesis. Norwegian University of Life Sciences, Ås, 2010b, pp. 86.

Meland S, Borgstrøm R, Heier LS, Rosseland BO, Lindholm O, Salbu B. Chemical and ecological effects of contaminated tunnel wash water runoff to a small Norwegian stream. Science of The Total Environment 2010; 408: 4107-4117.

Moore TLC, Hunt WF. Ecosystem service provision by stormwater wetlands and ponds - A means for evaluation? Water Research 2012; 46: 6811-6823.

Novotny EV, Stefan HG. Road Salt Impact on Lake Stratification and Water Quality. Journal of Hydraulic Engineering-Asce 2012; 138: 1069-1080.

Roe HM, Patterson RT. Arcellacea (Testate Amoebae) as Bio-indicators of Road Salt Contamination in Lakes. Microbial Ecology 2014; 68: 299-313.

van der Oost R, Beyer J, Vermeulen NPE. Fish bioaccumulation and biomarkers in environmental risk assessment: a review. Environmental Toxicology and Pharmacology 2003; 13: 57-149.

Vikan H, Meland S. Purification Practices of Water Runoff from Construction of Norwegian Tunnels—Status and Research Gaps. In: Rauch S, Morrison G, Norra S, Schleicher N, editors. Urban Environment. Springer Netherlands, 2013, pp. 475-484.

Vollertsen J, Åstebøl SO, Coward JE, Fageraas T, Madsen HI. Monitoring and modelling the performance of a wet pond for treatment of highway runoff in cold climates. In: Morrison GM, Rauch S, editors. Highway and urban environment: Proceedings of the 8th Highway and Urban Environment Symposium. Springer, Cyprus, 2006, pp. 499-509.

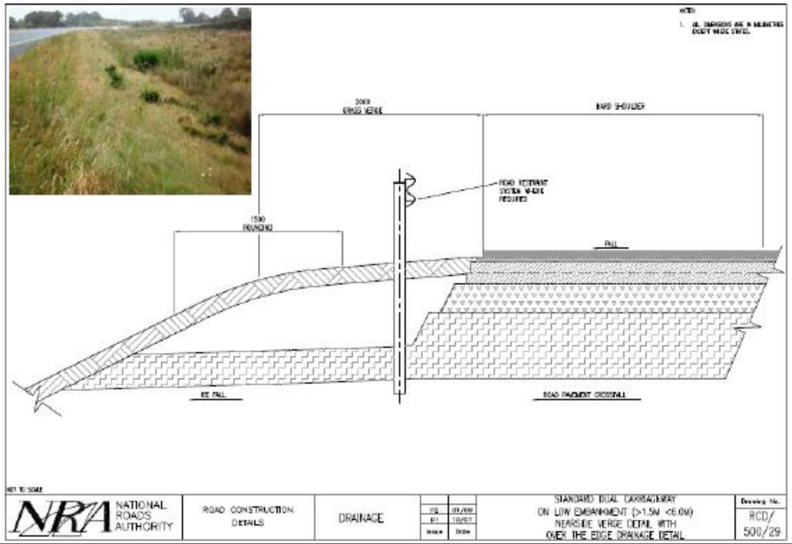
Wheeler AP, Angermeier PL, Rosenberger AE. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. Reviews in Fisheries Science 2005; 13: 141-164.

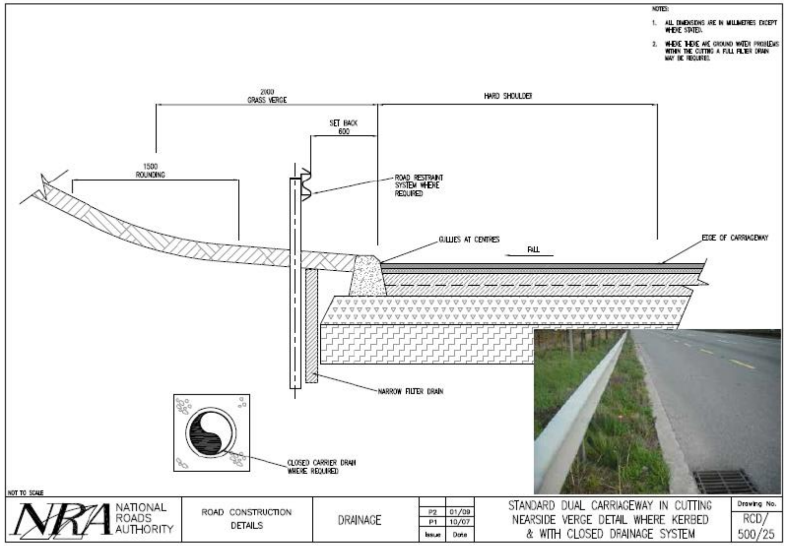
Yannopoulos S, Basbas S, Giannopoulou I. Water bodies pollution due to highways stormwater runoff: measures and legislative framework. Global Nest Journal 2013a; 15: 85-92.

Yannopoulos SI, Grivaki G, Giannopoulou I, Basbas S, Oikonomou EK. Environmental impacts and best management of urban stormwater runoff: measures and legislative framework. Global Nest Journal 2013b; 15: 324-332.

Åstebøl SO. Overvåkning av rensebasseng for overvann fra E6 Skullerudkrysset i Oslo, 2003 - 2004 (In Norwegian). Vegdirektoratet Utbyggingsavdelingens rapportserie. Statens vegvesen, Oslo, 2004, pp. 29.

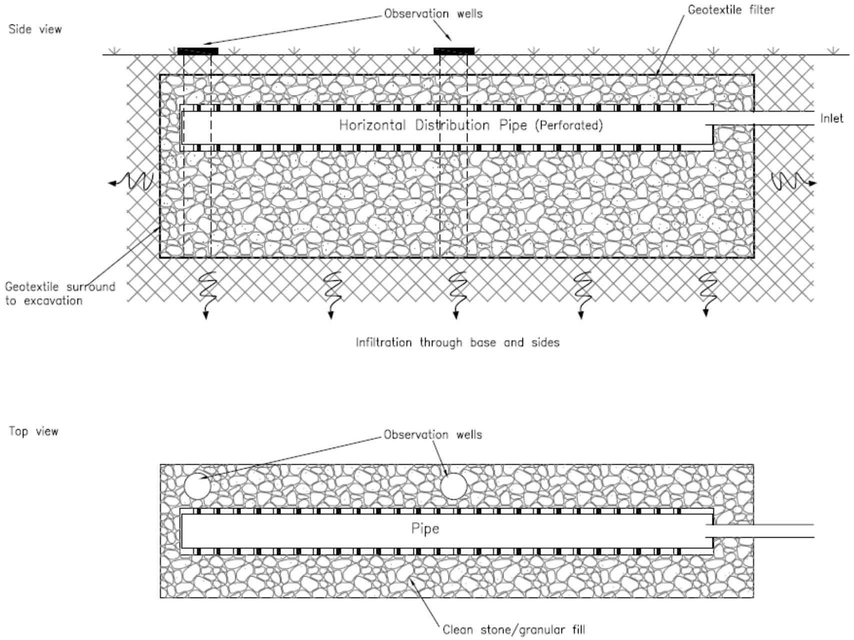
Appendix I: Examples of treatment facilities

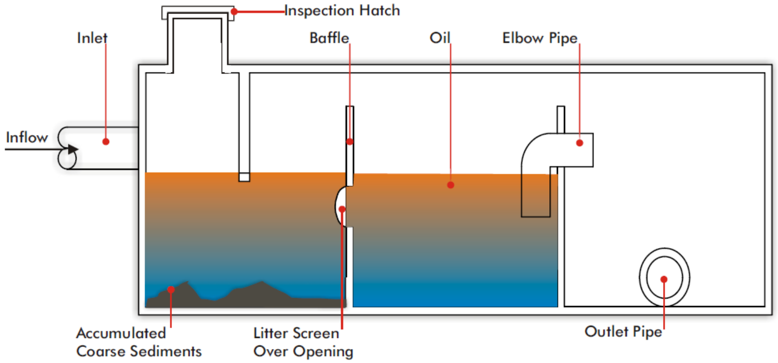
Name	Illustration	Treatment provided
Over-the-edge drainage Flow of surface water from the roadway over the edge of the roadway, down embankments, into an interceptor ditch or open drains/ditches etc.		**<u>Flow attenuation:</u>** Some attenuation of flows discharged to downstream receiving waters due to slower runoff down vegetated embankments and retention in interceptor channels **<u>First flush:</u>** Some treatment due to vegetated embankments **<u>Pollutants:</u>** Poor treatment provided if draining directly into watercourse or ground. Over-the-edge drainage over embankments can provide pre-treatment for combined filter drains by trapping suspended solids.

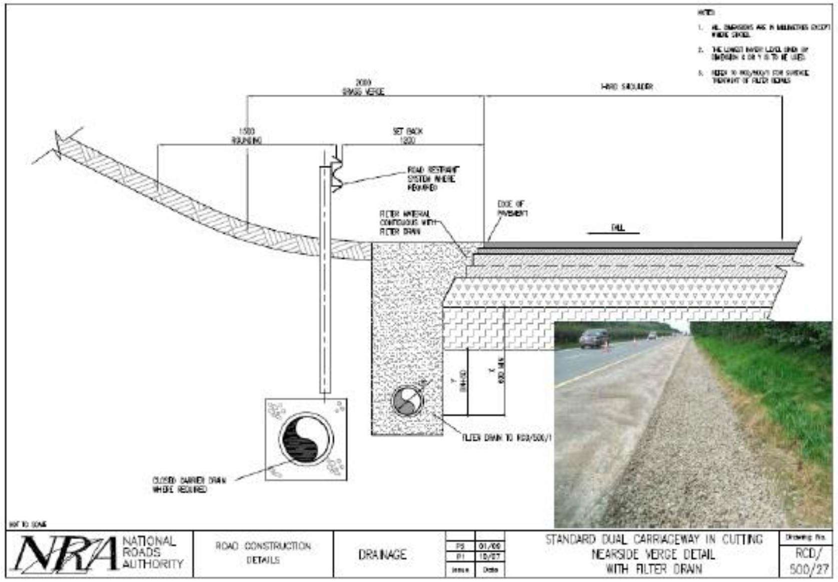
Name	Illustration	Treatment provided
Kerbs and gullies with a sealed carrier pipe Kerbs laid to the edge of the roadway constrain drainage to the edge of the road, where gullies collect runoff and discharge into a sealed carrier pipe		**Flow attenuation:** Minimal **First flush:** No special provision for first flush **Pollutants:** Gullies can capture potentially contaminated sediments during normal rainfall events. No biological treatment Petrol interceptors normally required prior to discharge to receiving waters

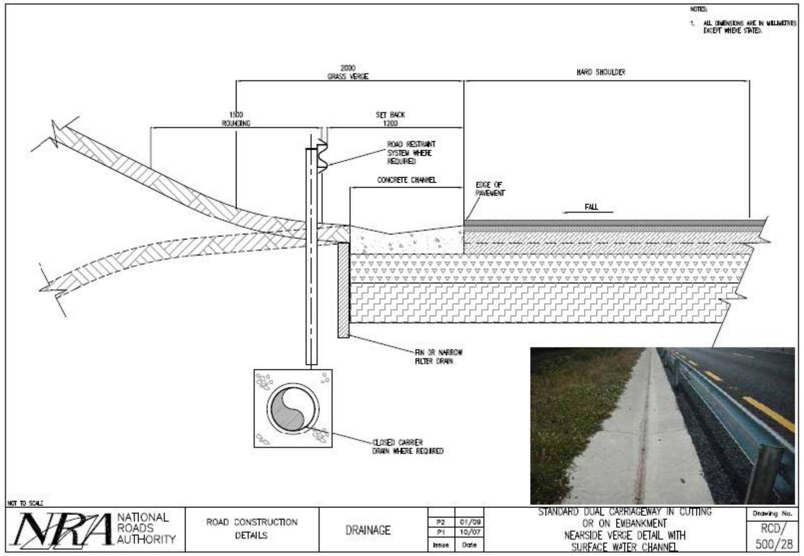
Name	Illustration	Treatment provided
Combined kerb and drainage block with a sealed carrier pipe Closed internal channel sections formed when contiguous precast concrete units, either in one piece or comprising separate top and bottom sections, are laid.		**<u>Flow attenuation:</u>** Some attenuation of flow, mainly due to the storage capacity of the design **<u>First flush:</u>** No special provision for first flush **<u>Pollutants:</u>** No biological treatment Petrol interceptors normally required prior to discharge to receiving waters

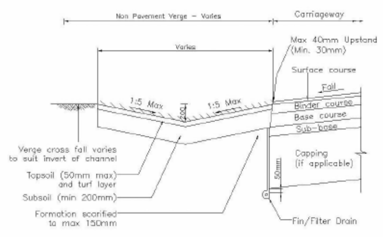
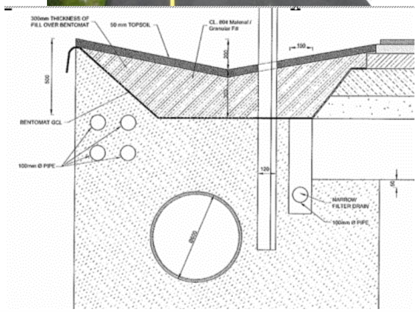
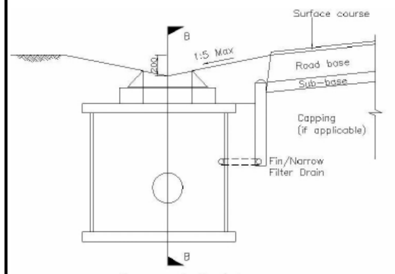
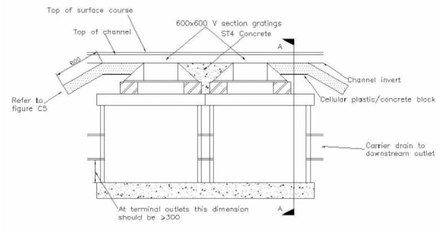
Name	Illustration	Treatment provided
Linear drainage channels Manufactured units flush with the carriageway, containing a drainage conduit beneath the surface into which surface water enters through slots or gratings		**Flow attenuation:** Minimal **First flush:** No special provision for first flush **Pollutants:** No biological treatment Petrol interceptors normally required prior to discharge to receiving waters

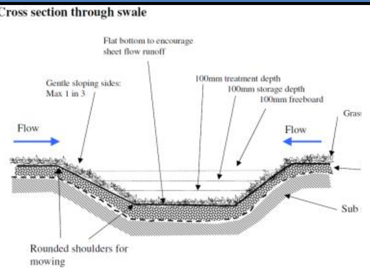
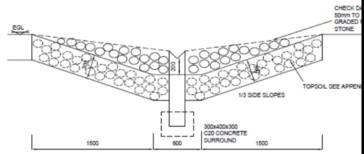
Name	Illustration	Treatment provided
Infiltration systems ***Soakaway*** A structure filled with media that facilitates efficient hydraulic discharge to the underlying ground ***Infiltration trenches*** Rock-filled pits or large tank structures designed to infiltrate run-off to the ground	 **Infiltration trench (DMRB)**	**<u>Flow attenuation:</u>** The storage capacity is normally designed to cope with peak runoff from design storm events to prevent flooding of the roadway. **<u>First flush:</u>** No special provision for first flush. Potential for contamination of groundwater. Consequently, infiltration systems require upstream pollution control. **<u>Pollutants:</u>** Minimal removal of pollutants, highly dependent on soil characteristic and depth of unsaturated zone beneath infiltration systems and groundwater. Any removal of pollutants by natural attenuation is due to the combined impacts of physical processes (e.g. filtration), chemical reactions (e.g. oxidation of sulphides), and biochemical transformations (e.g. the degradation of compounds under aerobic or anaerobic conditions). Pre-treatment is essential for effective use of infiltration systems as even a small suspended solid will clog the system.

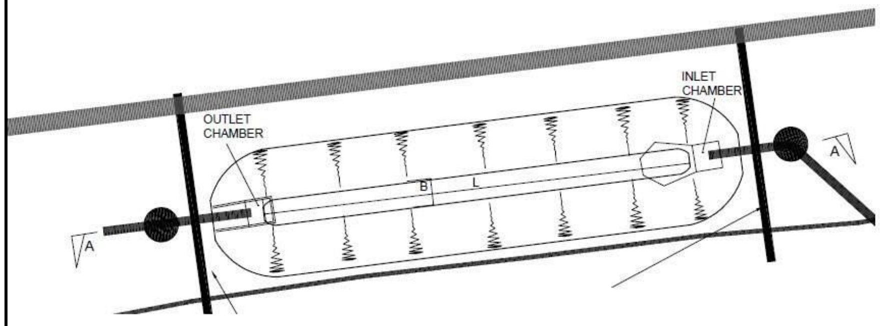
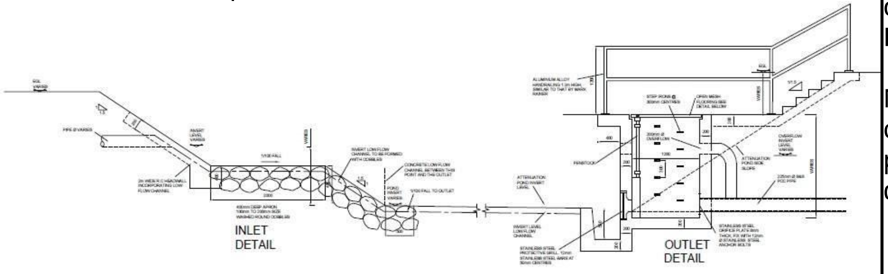
Name	Illustration	Treatment provided
Petrol interceptor A trap used to filter out hydrocarbon pollutants from runoff	 	**<u>Flow attenuation:</u>** Minimal **<u>First flush:</u>** Well maintained petrol interceptors treat first flush. Without regular maintenance, the system quickly reaches capacity, when hydrocarbon and solid pollutants are re-entrained into the flow, rendering the device ineffective with the risk of high concentrations of toxic pollutants discharged in heavy runoff. **<u>Pollutants:</u>** Removal of coarse sediments due to settlement Retention of hydrocarbons, which need to be removed by regular maintenance

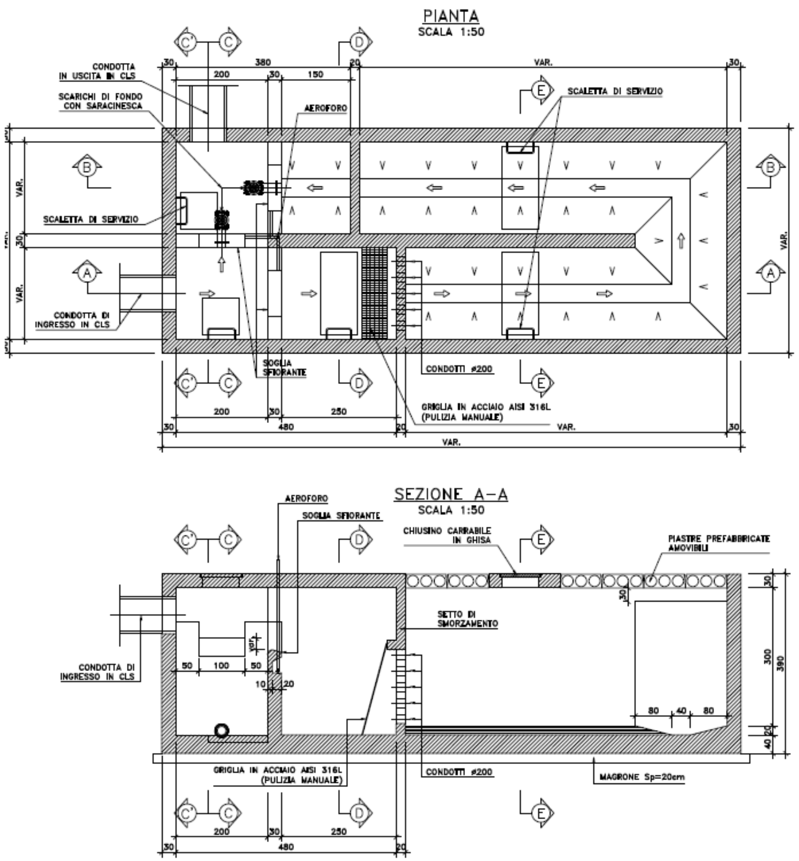
Name	Illustration	Treatment provided
Combined filter drains Linear drains consisting of trenches filled with a permeable material, often with a perforated pipe in the base of the trench to assist drainage, to store and conduct water; they may also permit infiltration.		**<u>Flow attenuation:</u>** Provides attenuation of runoff flows **<u>First flush:</u>** No special provision for first flush. Risk that large fuel oil spills can be discharged into a nearby watercourse through filter drains. **<u>Pollutants:</u>** Provides limited treatment, with the removal of suspended solids Prone to clogging. Does not provide biological treatment. Some pre-treatment should be provided upstream of the filter drain.

Name	Illustration	Treatment provided
Surface water channels Surface water channels are normally of a triangular concrete section, usually slip-formed, set at the edge of the hard strip or hard shoulder and flush with the road surface		<u>**Flow attenuation:**</u> Minimal <u>**First flush:**</u> No special provision for first flush <u>**Pollutants:**</u> No treatment

Name	Illustration	Treatment provided
Grassed surface water channel Shallow triangular or trapezoidal surface water channel lined with grass. At suitable points along the channel, water is discharged into a separate carrier pipe	DMRB  **M18 Gort to Crusheen**      **Typical Outlet Detail (DMRB)**	**<u>Flow attenuation:</u>** The grass reduces flow velocity, providing better flow attenuation than concrete channels. **<u>First flush:</u>** No special provision for first flush **<u>Pollutants:</u>** Slower velocities facilitate deposition of suspended sediments and associated suspended polluting heavy metals, e.g. lead, copper, zinc, and cadmium. Sediments are also trapped by grass blades.

Name	Illustration	Treatment provided
Swale Wide, shallow Grass lined gently sloping depressions designed to convey water to infiltration or a watercourse.	 *Reference Design Guide for Sustainable Urban Drainage Systems, Neath Port Talbort County Borough Council.* *Cross-section of swale with check dam*  TYPICAL SWALE CROSS SECTION SHOWING CHECK DAM ELEVATION (CHECK DAMS AT 10m CENTRES) *Swale Design for N6 Loughrea Bypass*  **Infiltration swale and erosion protection**	**<u>Flow Attenuation:</u>** Controls peak discharges by reducing run-off velocity. 8–10 minute residence time. **<u>First Flush:</u>** Pollutants and debris can be retained on the surface. Swales offer better protection than filter drains for management of large spillage of hydrocarbons. Intense storms may lead to situations where the previously accumulated suspended solids are washed downstream. **<u>Pollutants:</u>** Traps pollutants via filtering effects of vegetation; good removal of suspended solids, heavy metal, organic compounds, and oils and greases. Suspended solid loadings can be reduced by over 50 per cent. Nutrient removal due to plant uptake is possible but considered poor treatment. Check dams can be incorporated into swales to reduce flow velocities further and also to improve performance and containment of pollutants from accidental spillage.

Name	Illustration	Treatment provided
Attenuation pond Ponds designed to attenuate flows so that downstream watercourses are not exposed to damaging flows that can cause erosive or flooding damage. Can be designed to be wet or dry when not in use.	 Plan of attenuation pond  Section A-A through attenuation pond	**<u>Flow attenuation:</u>** Designed to attenuate flows by storage **<u>First flush:</u>** First flush can be contained in the pond **<u>Pollutants:</u>** Treatment is a secondary function of attenuation ponds. By retaining storm water for a period, some treatment will be achieved by the settlement of suspended solids. Moderate removal of suspended solids, heavy metals, organic compounds, oils and greases by settlement. Effectiveness of treatment depends on residence time. Nutrient removal due to plant uptake is possible but considered poor treatment, as it is dependent on plants present in the pond, and is likely to occur only during growing season.

<table>
<tr><th>Name</th><th>Illustration</th><th>Treatment provided</th></tr>
<tr>
<td>Settlement ponds and tanks
Open permanent water bodies or underground tanks that store excess water for long periods, allowing particle settlement and biological treatment, prior to discharge into the receiving watercourse, which may be sensitive receiving waters.</td>
<td>

Plan and section of a typical concrete settlement tank</td>
<td><u>Flow attenuation:</u>
Attenuation and storage of runoff. Designed to hold water for 14–21 days.

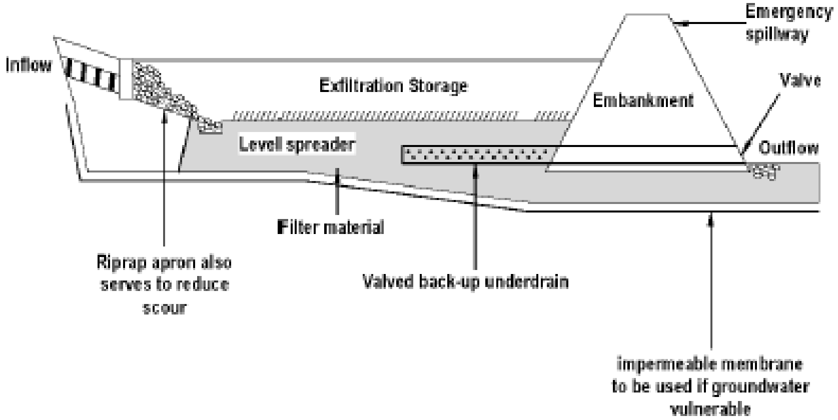
<u>First flush:</u>
Designed to accept and treat first flush without overtopping.

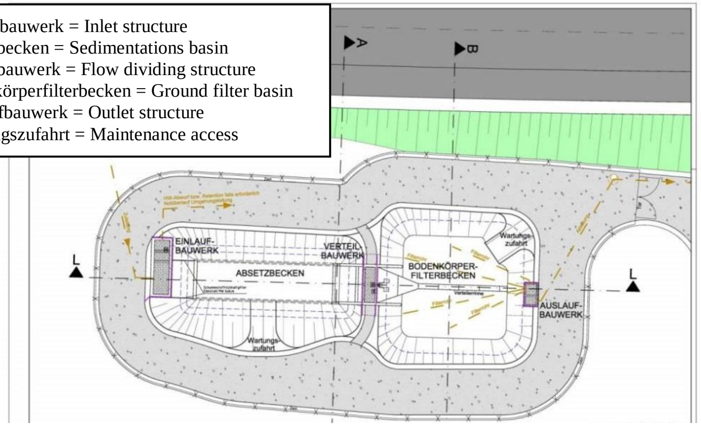
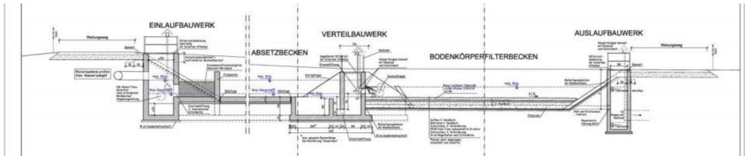
<u>Pollutants:</u>
Very effective for pollutant removal

Good removal of suspended solids and associated heavy metals by settlement

Moderate removal of oils and greases by settlement, adsorption, and biodegradation

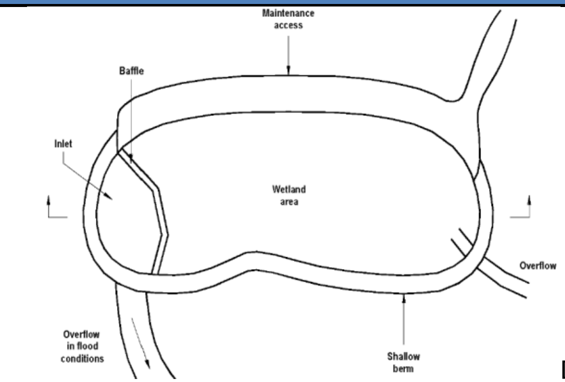
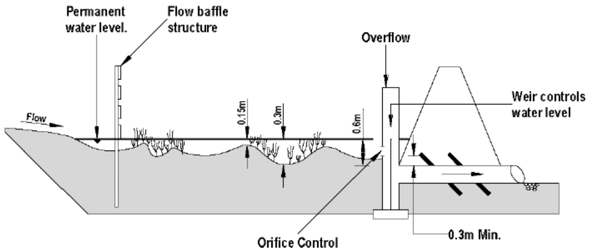
Poor to moderate nutrient removal. Depends on plant uptake during growing season.
Some tanks are designed to retain oils in the tank on the water surface.</td>
</tr>
</table>

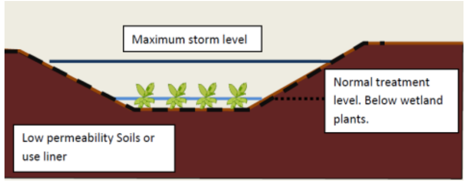
Name	Illustration	Treatment provided
Infiltration basin A pond that retains storm water flows and allows the water to percolate through a filter layer, which may typically comprise porous material, such as gravel. The water may then be directed to a surface water outfall, or it may continue to percolate through to groundwater.	 **Sand filter basin**  **Infiltration Basin** (DMRB)	**<u>Flow attenuation:</u>** Infiltration basins attenuate flows with a capacity that can cater for low return period rainfall events such as a 1-in-10 or 1-in-30 year event. **<u>First flush:</u>** Designed to treat first flush, with a bypass for flows that exceed the capacity of the basin **<u>Pollutants:</u>** Good removal of suspended solids and associated heavy metals by filtering and settlement Moderate to good removal of oils and greases by filtering, adsorption, settlement, and biodegradation Poor nutrient removal

Name	Illustration	Treatment provided
Hybrid plant settlement and infiltration basin Sedimentation basin followed by infiltration basin	Einlaufbauwerk = Inlet structure Absetzbecken = Sedimentations basin Verteilbauwerk = Flow dividing structure Bodenkörperfilterbecken = Ground filter basin Auslaufbauwerk = Outlet structure Wartungszufahrt = Maintenance access   	**<u>Flow attenuation:</u>** Provides flow attenuation **<u>First flush:</u>** Designed to accept and treat first flush without overtopping **<u>Pollutants:</u>** Provides high pollutant-removal efficiencies Good removal of suspended solids and associated heavy metals by filtering and settlement Good removal of oils and greases by filtering, settlement, adsorption, and biodegradation

<table>
<tr><th>Name</th><th colspan="2">Illustration</th><th>Treatment provided</th></tr>
<tr><td rowspan="3">Hybrid plant settlement and infiltration basin (continued)</td><td>
Dry sedimentation basin</td><td>
Wet sedimentation basin</td><td rowspan="3"></td></tr>
<tr><td>
Water-dividing structure, with throttle (red pipe), Distribution gutter crosswise to the pipe.</td><td>
Distribution gutter, infiltration basin</td></tr>
<tr><td>
water dividing structure (background) + infiltration basin + outlet structure (in front)</td><td></td></tr>
</table>

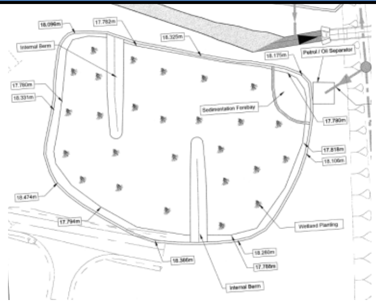
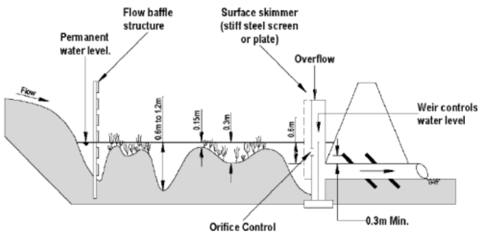
Name	Illustration	Treatment provided
Runoff treatment plant Settlement and filtration	 Technical water protection plant, sedimentation basin (*front*), filter basin (*back*), water dividing structure (*between the basins*)  Technical filter with liquid level interrupter	**Flow attenuation:** Provides flow attenuation **First flush:** Designed to accept and treat first flush without overtopping **Pollutants:** Provides high pollutant-removal efficiencies Good removal of suspended solids and associated heavy metals by filtering and settlement Good removal of oils and greases by filtering, settlement, adsorption, and biodegradation

Name	Illustration	Treatment provided
Constructed wetland (surface flow) Constructed SF wetlands are basins that are usually planted with common reed swamp vegetation and are permanently saturated open-ended or closed basins, or low lying level ground.	 DRMB  DRMB	**<u>Flow attenuation:</u>** Provides flow attenuation **<u>First flush:</u>** Designed to accept and treat first flush without overtopping **<u>Pollutants:</u>** Provides high pollutant-removal efficiencies Good removal of suspended solids and associated heavy metals by filtering and settlement Good removal of oils and greases by filtering, settlement, adsorption, and biodegradation Moderate to good nutrient removal due to plant uptake

Name	Illustration	Treatment provided
Linear wetlands A wet swale or ditch that runs along the side of a road embankment populated with wetland plants.	 	**Flow attenuation:** Flows enter the linear wetland via an over-the-edge flow with some storage capacity in the wetland. **First flush:** First flush will be spread across the length of the linear wetland and a greater surface area. This should have less impact than concentrated point discharges. **Pollutants:** Treatment similar to constructed wetlands.

Name	Illustration	Treatment provided
Constructed wetland (sub-surface flow) Constructed SSF wetlands are essentially basins filled with porous material through which water flows. The porous material is kept at saturation, up to an appropriate water level, and is usually planted with common reed swamp vegetation	Not normally used for treatment of road runoff	**Flow attenuation:** Provides flow attenuation, which is limited by the volume of porous media **First flush:** Should be designed to accept and treat first flush without flooding the surface of the wetland bed **Pollutants:** Provides high pollutant-removal efficiencies Good removal of suspended solids and associated heavy metals by filtering Good removal of oils and greases by filtering, adsorption, and biodegradation Good nutrient removal due to plant uptake Very limited operational life due to rapid 'clogging' of the wetland substratum

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

Name	Illustration	Treatment provided
Hybrid ponds Hybrid ponds are a combination of treatment systems, where the aim is to combine the benefits of the systems.	 Plan of a hybrid wetland for attenuation and pollution control constructed for M18 Gort to Crusheen Motorway.  Schematic section through hybrid pond (DMRB)	**Flow attenuation:** Provides additional flow attenuation by combining ponds, wetlands, and infiltration basins systems **First flush:** First flush can be contained in a buffer such as sedimentation forebay. **Pollutants:** Hybrid systems with wetlands provide high pollutant-removal efficiencies Treatment efficiencies are increased by internal berms to regulate flowpaths and promote different habitats to sustain different plants for improved removal of nutrients.

Appendix II: Future research needs

The present table gives an overview of knowledge gaps and research needs identified by the members of TG I5 (Water Quality) through individual work, two meetings conducted in 2015 and 2016, and the workshop held in Stockholm in January 2015 (with invited participants from Germany, Poland, and the UK). A total of six research topics was identified during the present work, covering risk assessment (1), the performance and cost-benefit of treatment systems for runoff water both in the construction and operation phase of the road network (2 and 3), the environmental impacts of de-icing chemicals (4), new and emerging chemicals (5), and climate change and water quality (6). Within these main topics, 18 proposals for future research needs were identified. In addition, one proposal was to perform meta-studies, which could cover most of the topics presented in the present report. The TG suggests that priority should be given to research within the areas of risk assessment (proposals 1–2), the performance and cost-benefit of treatment systems (proposals 3–6), and road salt (proposals 11–13).

Table A1: Proposal of future research needs. The table gives a brief overview of the various research topics and subtopics. All the proposals are of both national and transnational interest. The proposals recommended for prioritisation by TG I5 (Water Quality) are marked in bold/underlined

Research topic	No.	Subtopic	Short description	Objective	Anticipated results
Risk assessment tools for deciding when road runoff should be treated	**<u>1</u>**	Establish models that predict the pollution concentrations and loadings in road runoff	Most countries use traffic (ADT) as a benchmark for when to treat road runoff. However, the relationship between the ADT and the pollution concentrations/loadings is rather poor. This not only reflects natural variability, but also that there are many other factors that are important (e.g. weather, sources, driving speed, etc.). To overcome this, TG I5 (Water Quality) believes that NRAs could learn from the modelling approach used for local air quality. These models are now considered good and adequate. Therefore, adopting and modifying such models could help NRAs to establish models that better explain the pollution concentrations/loadings in road runoff.	To establish models that could be used to decide when to treat road runoff	The development of models that could be used in risk assessments and decision-making. This would be important in terms of cost-benefit (e.g. to prevent the over-provision of measures to mitigate perceived negative impacts for protection of water bodies). Decision-making would be more science-based.
	<u>2</u>	Establish methods for assessing the water bodies' vulnerability to polluted runoff	A water body's vulnerability to pollutions depends on several hydro morphological, physicochemical, and biotic factors. As these factors vary between different water bodies, different water bodies will also vary accordingly. Thus, it is important to develop tools (e.g. flow sheets) that could help road planners decide whether a water body should be protected from road runoff or not (also from runoff events during road construction). The aim is to use data available from the characterisation of waters in the EU WFD.	To establish a method that could be used to classify and determine whether a water body is vulnerable or not in terms of polluted runoff from the construction and operation of roads	The development of methods that could be used in risk assessments and decision-making. This would be important in terms of cost-benefit (e.g. prevent overprovision of water bodies and misdirection of the limited resources available). The decision-making would be more science-based and

Research topic	No.	Subtopic	Short description	Objective	Anticipated results
					in line with the EU WFD.
The performance and cost-benefit of treatment systems for polluted runoff including tunnel wash water	3	Increase knowledge of the treatment performance and cost-benefit of existing treatment systems (e.g. SUDS) and more recently built technically advanced treatment systems	Blue-green solutions, also known as Sustainable Urban Drainage Systems (SUDS), have been used for some decades now for the treatment of road runoff. A variety of methods exist, and more recently, more technical treatment facilities have been built. There is a need for up-dated and new knowledge about their performance and cost-benefit analysis that takes into account the construction and operation costs. A good comparison of typical blue-green solutions that mimic nature and technical systems is lacking.	To gain increased knowledge about the performance and cost-benefit of existing and commonly applied methods such as SUDS and more advanced technical systems	Increased and up-dated knowledge about existing treatment systems and more recently advanced technical systems. The results will be important for NRA water management in terms of helping NRAs to decide how to treat road runoff.
	4	The treatment performance and cost-benefit of commercially available technical filter materials compared with soil filters	Commercial filters are believed to have various advantages over humus/soil filter basins. It is expected that basins with commercial filter material require less space. Moreover, as they are not vegetated, they are thus easier to maintain (e.g. mowing / vegetation control is not necessary). However, this is more or less based on assumptions than on real evidence. Therefore, increased knowledge about how commercially available filter material compares with soil filters is needed.	To compare the performance of commercial technical filters and soil filter material. Treatment performance and cost-benefit will be important.	Increased knowledge about commercial technical filters. The results will be important for NRA water management in terms of helping NRAs to decide how to treat road runoff.
	5	The long-term performance of soil filters in treatment facilities. Efficiency versus investment and operational costs.	Some countries (such as Austria, France, Germany, and Switzerland) use soil-filter treatment. However, preliminary experience shows a huge variation in performance. There are some assumptions regarding this variation, but these are not well described or documented. In addition, little is known about the return on investment for both the economy and the environment.	To establish a transnational database where monitoring data (e.g. performance, costs etc.) is stored and available to all CEDR countries. The collection of data may be limited to one or two CEDR strategic plan periods (i.e. 4–8 years).	A more accurate and transnationally supported description of best case and best practice regarding soil treatment
	6	Alternative and innovative treatment methods for tunnel wash water	The treatment of tunnel wash water, which has proven to be more polluted and concentrated than normal road runoff, may be relatively complicated and costly. For example, countries like Austria and Switzerland use sedimentation and filtration (e.g. mobile treatment trucks). However, countries like Norway and Sweden use sedimentation for treatment albeit until now only in major tunnels close to cities. There is a need for more innovative high-performance, cost-efficient solutions.	To compare the treatment performance of existing treatment methods, i.e. both sedimentation and filters and flocculation chemicals, and to obtain information about new and innovative high-performance, cost-efficient	Increased knowledge about tunnel wash water treatment that meets strict requirements while still being cost efficient. This would provide important input for the management of tunnel wash water.

Research topic	No.	Subtopic	Short description	Objective	Anticipated results
				solutions	
	7	Treatment methods that reduce the impact of high levels of chlorides	De-icing chemicals such as NaCl are extensively used during winter maintenance. The impact of road salt on surface water bodies and ground water is reported worldwide. Chloride is highly soluble and mobile and is not retained—only to some extent diluted—by current treatment methods. Hence, solutions that could efficiently mitigate the impact of road salt are needed.	To identify technologies that could mitigate the impact of road salt in a cost-efficient way	The establishment of alternative water treatment systems that could mitigate salt impacts in an economical and technically acceptable manner
The performance and cost-benefit of treatment systems for runoff during road construction including tunnelling water	8	Denitrification of water from construction sites contaminated with undetonated explosives	Ammonium nitrate (NH_4NO_3) is commonly used as an explosive in the construction of roads. Approximately 15% of the explosive is undetonated. Environmental authorities set restrictions on nitrate release to recipients vulnerable to eutrophication. There are, however, currently no appropriate methods for denitrification for construction sites.	To identify or develop technologies for the denitrification of water that can be used on construction sites.	The identification of treatment technologies that may be suitable for the denitrification of runoff water from construction sites including tunnelling water. The results will be important for meeting the criteria and EQS's set by environmental authorities and the EU WFD.
	9	Treatment methods for runoff water during construction	A range of treatment methods such as earth ponds, swales, basins, and technical methods such as pH-adjustment, flocculation, etc. are used to mitigate runoff during the construction of roads. This is believed to provide sufficient protection of water bodies. However, their performance is rarely documented and evaluated scientifically.	To increase knowledge about the performance and efficiency of various treatment methods used during road construction	Increased knowledge that will provide important input for guidelines and best practice in terms of road-building projects.
	10	Recycled material such as concrete and asphalt and other waste materials in the construction of new roads may leach hazardous substances into the aquatic environment. The risk of leaching may be reduced by using safety measures, e.g. technical safeguard material (TSM)	Recycled material such as concrete and asphalt and other waste materials may often be favourable because of the cost savings, reduced CO_2-emissions, etc. that they bring. However, these materials may pose a threat to the aquatic environment (and surrounding soil) due to the leaching of hazardous substances. This may be solved by taking additional safety measures (technical safeguard material (TSM)). Experience and knowledge of TSMs is, however, lacking. In addition, innovative cost-beneficial solutions that improve safety are needed.	To gain increased knowledge about the risks associated with re-using waste material in road construction. To evaluate the performance of safety measures such as TSM and gain information about new and innovative TSMs.	The identification of methods that stimulate the re-use of waste materials in road construction. This may cut costs and reduce both land consumption and CO_2 emissions.

The environmental impacts of de-icing chemicals	**11**	Chemical impacts and stratification in lakes and streams due to the use of road salt (NaCl)	Road salt may have a negative impact on small water bodies such as lakes and ponds. For example, elevated chloride concentrations may cause chemical stratification and oxygen depletion in the hypolimnion of lakes and ponds. Such impacts have been identified in several lakes in Nordic countries and North America. However, little attention has been paid to these issues in other European countries.	To identify the extent to which road salting has a negative impact on European water bodies	Increased knowledge and awareness of the environmental impact of road salting, which would motivate NRAs to develop more environment-friendly winter maintenance methods. The results would also be highly relevant for the environment agencies in terms of compliance with the EU Water Framework Directive.
	12	Chemical impacts on ground- and surface water bodies due to the use of alternative de-icing chemicals	Due to the environmental concerns and damage caused by road salting, alternative de-icing chemicals may be needed. Some countries, e.g. Sweden, have established Environmental Quality Standards (EQS) and the Swedish NRA is obliged to take measures if the EQSs are violated. There has been some research and testing of alternative de-icing chemicals in Finland and to a lesser extent in Sweden and Norway. There is, therefore, a need to compile and review present international knowledge about alternative de-icing chemicals.	To identify whether, and if so what and to what extent negative environmental impacts on surface- and ground water bodies arise due to the use of alternative de-icing chemicals	Increased knowledge and awareness of the environmental impacts of using alternative de-icing chemicals. The results would be highly relevant for the environmental agencies and the EU Water Framework Directive. In addition, the objective should also be to make clear recommendations regarding when and where to use alternative de-icing chemicals and, of course, which chemical de-icer to use.
	13	Cost-benefit analyses: comparisons of road salt and alternative de-icing chemicals and other physical and mechanical measures	There are many possible ways of reducing the risk of accidents in winter conditions, e.g. sanding, increased ploughing intensity, speed limitations, vehicle requirements, etc. However, road salt (NaCl) is the by far most preferred measure as it is considered cheap and easy to use. However, it is not always shown, beyond any reasonable doubt, that road salt is the most cost-effective method *if* the impact on the environment is taken into account, especially in water protection areas and Natura 2000 areas. Consequently, cost-benefit analyses that take environmental impacts into account are needed.	To investigate, evaluate, and determine the *overall* costs (including environmental costs) of various chemical, physical, and mechanical measures to reduce the risk of accidents in winter conditions while causing minimum environmental harm	Increased knowledge and awareness of the socio-economic costs using different methods to reduce the risk of accidents during winter conditions. The objective should also be to make clear recommendations regarding when and where to use different alternative methods (acceptance from authorities;

					application).
New and emerging chemicals	14	New technology and materials in the car industry will most likely change the content and composition of pollutants in road runoff.	Vehicle technology changes rapidly (consider, for example, the development of electric, hybrid hydrogen cars, and biofuels). The question as to whether our roads are suitable for future technologies is being asked in many domains. However, this question should also be addressed in terms of the impact on water bodies receiving road runoff. The anticipated reduction in emissions may reduce the need for treatment, but new and emerging chemicals may contradict this. There is therefore a need for more knowledge and projections on how this change will affect future water management.	To increase the knowledge and awareness of new and emerging chemicals used in the car industry. To model the rise of e-Mob and partial e-Mob, lubricants, fuel, recuperation instead of brake pad abrasion and to identify all other influences.	Increased knowledge about future water treatment requirements for road runoff. It will also provide input regarding what to include in e.g. monitoring programmes.
	15	New technology and materials in the construction industry will most likely change the content and composition of pollutants in road runoff.	New chemicals are rapidly introduced in the construction industry, e.g. various coating materials including nano-materials/technology, flame-retardants, accelerators, etc. Some are introduced as substitutes for chemicals that are banned. However, the knowledge regarding the fate and impact of these new chemicals on the environment is limited.	To increase the knowledge and awareness of new and emerging chemicals used in the construction industry. To review existing products/materials on the market, emphasising priority pollutants and leaching tests.	Future requirements for the water treatment of road runoff. It will also provide input regarding what to include in monitoring programmes.
	16	The screening of new and emerging chemicals in road runoff	Particles, Metals, PAHs, salt, and nutrients are the contaminants that have been prioritised by the research community (and regulators). Less is known about new and emerging chemicals, which is why research into loadings, concentrations and the behaviour and fate of such pollutants is needed.	To increase the knowledge about new and emerging chemicals and to determine whether the current treatment practice is satisfactory.	Increased knowledge about the content of pollutants in road runoff. This will be relevant for NRAs, the EU WFD, and the EU chemical agency's work on REACH.
	17	Micro-plastic in the environment has attracted a lot of attention and is now considered a problem worldwide. Tyres are believed to be a significant source of plastic in the environment, but are there other sources from roads and traffic?	Plastic and micro-plastic have attracted great attention at international level regarding their impact on the aquatic and, in particular, the marine environment, not only as a litter problem, but also as substances that have both a physical and chemical impact on organisms throughout the entire food-web. In addition, plastic is very resistant to degradation. Tyres are considered to be a major contributor to the presence of micro-plastic in the environment. There is, however, little knowledge about their fate in the environment: amounts released and transported from the roads, their distribution in the various aquatic compartments (water, sediment…), to which extent they are retained in the road verge/trenches and various treatment facilities (ponds, wetlands, infiltration systems etc.).	To determine the extent to which roads and traffic contribute to the world-wide environmental problem of plastic and micro-plastic.	Increased knowledge about micro-plastic in the environment.

Climate change and water quality	18	Climate change, with increased and intense precipitation, affects road runoff in terms of road runoff volumes (flooding) and pollution loadings/concentrations.	Climate change, with increased and intense precipitation, affects road runoff, may have an impact on both road runoff volumes (flooding) and pollution loadings/concentrations. It is unclear whether the current treatment technology and management are sustainable and sufficient with regard to climate change.	To evaluate the present treatment technology and management in the context of a changing climate.	The results will help NRAs adapt and develop current water management with regard to climate change.
Meta Studies	19	Transnational coordination of existing research results	Various NRAs have already done a lot of research on various water management topics. However, the availability of the results is limited because the results are published in reports written in native languages. Availability is also limited because common library/search engines do not index such reports (grey literature).	To review, compile, and disseminate research results already available in the various NRAs.	Increased common knowledge among NRAs. This may harmonise current water management practices in terms of when and how to treat contaminated runoff when building and operating the road network.

Ref: CEDR report 2016/01 - Management of contaminated runoff water
ISBN: 979-10-93321-18-9

Conference of European Directors of Roads
Avenue d'Auderghem 22-28
1040 Brussels, Belgium

e-mail : information@cedr.eu
Tel. : + 32 (0) 2 771 2478