Interreg North-West Europe
Co-funded by the European Union

Rural Roadwater Rescue

Rural_Roadwater_Rescue
Scoping report

D 1.1.1 Scoping report: existing experiences & synergy projects on roadwater knowledge & technologies

Period 2

31.10.2024

Rijkswaterstaat
Ministry of Infrastructure and Water Management

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

DVGW

TZW
Technologiezentrum Wasser

Vlaanderen
is milieu

imec

CK

Summary

1 Introduction

This report is established as a deliverable of the small-scale INTERREG NWE project “Rural Roadwater Rescue” (RRR). The RRR-project aims to deliver a transnational strategy extending the role of roads to support rural water systems. The project partnership consists of Rijkswaterstaat (lead partner), TZW (German Water Centre), CEREMA, IMEC, Vlaamse Miliemaatschappij and Corporatie Kloostersland. More information on this project can be read on https://rural-roadwater-rescue.nweurope.eu/

This report is part of the scoping activity for RRR. The first aim of this report is to document the transnational pool of existing knowledge in the partnership. As every partner brings previous projects and experiences to the table, this scoping exercise resulted in a starting base for joint and "eye-to-eye" cooperation. This return of experience is done in chapter 2 for the countries of the main partners Flanders, France, Germany and the Netherlands. The report focuses on the practices and knowledge from highways, considering that the possibilities of reuse of the stormwater from those roads should be the most challenging since they support a high traffic.

In chapter 3 we present an overview of existing digital initiatives relevant to road-adjacent water management and explores how dataspace concepts can support the development of climate-adaptive water hubs near road infrastructures.

We defined the scope concerning the technologies of collection and use of runoff water and the technical state of the art in road/highway infrastructure technology. In this process 7 elements were identified for a balanced roadwater management to face the challenges of climate change :

1. **Prevention**: How to prevent the pollution of roadwater ?
2. **Collection**: How is roadwater collected ?
3. **Cleaning / Treatment**: What are the cleaning/treatment processes used ?
4. **Storage**: Is there a storage of those waters ?
5. **Use / Re-use**: Which local actors have interest in roadwater ? For what use ?
6. **Distribution**: How is roadwater distributed to users ?
7. **Ecosytem balance**: How does (re)use of roadwater contribute to ecosystem balance ?

Combined in one location they make a local water system we called Climate Adaptive Waterhubs.

The partnership added to this transnational pool of knowledge the results and analysis of a survey, described in chapter 4. This survey was built on the identified 7 elements of a climate adaptive water hub and open to the public and associated partners were invited to collect feedback on road stormwater management practices. Chapter 5 summarizes Road Water Practices in the Partner Countries following the 7 elements.

The second aim of this report is to use the collection of information as a start-up for the upcoming project activities towards a strategy for climate adaptive water hubs in the territory of North West Europe, eg legal boundaries, technical solutions, possible uses and users. With this in mind, chapter 6 explores factors to be considered when establishing pilot sites for future local users. Relevant links per country are collected in chapter 7.

This report ends with two **chapters** with summaries of research projects or studies in France and Flandres on the characterization of road pollutants to tackle the problem of roadwater pollution. Tables and figures in these chapters start again with 1.

The partnership hopes that this deliverable will be an inspiring source of information for the reader.

2 Stormwater Management Policies and Practices

2.1 Overview

This chapter is an overview of roadwater management policies and practices in the partner countries *as is*. This summary of practices should help to highlight the issues to be addressed and the questions to be asked for the forthcoming survey.

The scope of this study focuses on heavy traffic highways, whose waters are renowned to be more polluted and subject to greater risks of accidental pollution.

Figure 1: Water arriving in a basin (Cerema)

2.2 Germany

In Germany, the Autobahn GmbH des Bundes is responsible for the management of 13.200 km of federal highways called “Autobahnen” or “BAB” (**B**undes**a**uto**b**ahn, short: “BAB”, often named “A <Number>”). They have 2 to 5 lanes in one direction, total lane length 59.000 km; total area 340 km² (data 2023). There are other national 1 or 2-lane roads (“Bundesstraßen” [B road], “Landstraßen” [L road], or “Kreisstraßen”) with a total lane length of 434.000 km (assuming 1 lane in each direction) which are not included in their area of responsibility. Each federal state, as well as cities or communities have a different road manager for these roads. Depending on the location of the federal highway, the time of the day and how frequently it is generally used, the daily traffic of vehicles (DTV) can vary from a minimum of 2.000 vehicles per day, to up to 240.000 vehicles per day.

It is mandatory, that the water volume, which cannot be naturally seeped due to the sealed highway must be recirculated to the water cycle on another way and there are technical regulations for the treatment of the roadwater before recirculation. The rules for roadwater discharge into water bodies are regulated for all kinds of roads (BAB, B roads and L roads) in the road drainage guideline 2021 (“Richtlinie für die Entwässerung von Straßen”, 2021), derived from the wastewater ordinance (“Abwasser-Verordnung, AbwV”) and monitored and approved by the local lower water authority (local = place of discharge or drainage). These regulations make it a requirement that pollutants must be taken into account when constructing a roadwater treatment plant. In addition, the regulations are often depending on the designation of a groundwater protection zone. Therefore, when working on highway projects, an analysis of the vulnerability of surface water and groundwater must be carried out. Roadwater treatment plants are designed with this vulnerability in mind to prevent the input of harmful substances to the environment. In the case of very strong water vulnerability, costly measures are put in place to combat water pollution by road runoff water.

Within RRR, 7 relevant elements in roadwater management have been defined. These are collection, cleaning / treatment, storage, distribution, use, prevention and ecosystem balance. For these, the following regulations are applicable in Germany:

In general, all **collection**, **storage** and **treatment** components are part of the road structure and are, for federal highways, in the responsibility of Die Autobahn GmbH. As mentioned above, a road interrupts the natural water cycle of rainwater infiltration, therefore the roadwater is compensated by infiltration to the groundwater somewhere next to the road. If infiltration is not possible, it is allowed to discharge the road water alternatively into a receiving surface water waterbody after a treatment to ensure the water quality is sufficient.

For **collection** of the roadwater, gullies are installed all along the BAB highways, see Figure 2. If waterproof asphalt is used, only the surface water is collected by gully installations as shown in Figure 2 A and B. In order to reduce noise from the traffic, sometimes large-pored asphalts are used, which let the water seep down to 5-6 cm. In this case, gully systems like shown in Figure 2 C and D are used, where drainages are also placed below the road surface to collect the seeped water.

Figure 2: Examples of gullies to collect roadwater from federal highways. A and B show the collection of surface road water, C and D show the collection of surface and seeped water in large-pored noise reducing asphalt.

The use of grassed ditches and gutters is recommended for reasons of cost and roadway stormwater treatment capacity. However, these structures do not have the purpose of water collection itself, they could be concreted to limit infiltration where there is a risk of erosion or where groundwater is at stake (e.g. in the case of water catchments). The design rules for evacuating rainfall are described in the named technical guideline of 2021 (currently in progress). The ditches are often dimensioned for rainfalls who have a probability of 1/10 to occur a given year. The direct shoulder infiltration of roadwater along existing highways is very uncommon and is successively converted to extended water treatment. In the case of infiltration systems, there may be special soil layers or plantings. Depending on the permeability of the soil, the soakaway must make up around ten to 20 percent of the total area.

Storage is done only temporarily: Since the rainwater cannot drain away as quickly as it falls, it must be temporarily stored or retained. For this, a certain retention area or storage volume is required. This is normally done by close-by water tanks, where a certain volume of water is shortly stored until a specific water level in the tank is reached, see Figure 3. Currently, the roadwater is either seeped away or drained into a receiving water as quickly as possible after treatment. There is no long-term water storage. But of course, also the basins provide storage capacity for accidental pollution in dry or rainy weather, and are partly waterproof (cemented) to avoid infiltration of pollutants. The sizing of retention basins is based on the best practices of urban stormwater management (grasping volume of 10, up to 100 annual flood events). In cases of heavy rain events and floodings or technical interruptions, additional buffer tanks and pipes are installed next to the highways to buffer extreme amounts of water as an intermediate storage, if a pump cannot pump the water into the wastewater system quickly enough (e.g. in tunnels).

Figure 3: First water collection tank and pumps, which are activated after a certain water volume is reached.

It is defined by law, that certain **cleaning / treatment steps** have to be installed beneath BABs to clean the roadwater. These steps can be applied at different stages of the whole process, depending on the special local conditions: For instance, often a pre-treatment step (oil separator, sedimentation) is directly applied at the collection/storage (Figure 3), as light substances (oils) will float on the water surface and are not further transported with the water. Pumps are automatically activated, as soon as a certain water level is reached and pump the water to sedimentation/retention or infiltration basins. If infiltration is not allowed, the basins are cemented. At the basins, the steps sedimentation, particle separation with sieves and grids and oil separation are always applied. This cleaning installation and the basins, especially/mainly if they have a cleaning function, must not dry out. The settling sludge has to be burned regularly, what had been done previously in the combustion chamber of brown coal-fired power plants. For B and L roads, mostly shoulder infiltration is performed. To allow the roadwater to flow to the road shoulders, these roads are constructed with a slightly domed surface.

At the point where the infiltrating road water enters the groundwater, it must be of a quality that does not affect the groundwater. This requires water testing by Autobahn GmbH, who must prove the sufficient water quality, at the seepage water entry point. The lower water authority of a federal state or city is in charge to approve an authorisation for infiltration. The requirements for groundwater quality can vary depending on how the groundwater is used. Also, depending on the requirements on the surrounding nature (for instance groundwater protection areas), infiltration will take place or not (depending on the extent of the protection status, protection zones 1 to 3, 1 has the highest claim). The treatment by infiltration of the water back to groundwater is the preferred possibility.

Figure 4: Sedimentation/ retention basin next to the federal highway A5 in south Germany.

Mostly, there are also extra basins for retention of oil and heavy particles in the case of accidents. The dimension of these basins is depending on the intervention time of civil security services. For these accidents, normally the closure of the complete system is possible. In Figure 4, a sedimentation basin is shown, in Figure 5 a scheme of treatment as given by law.

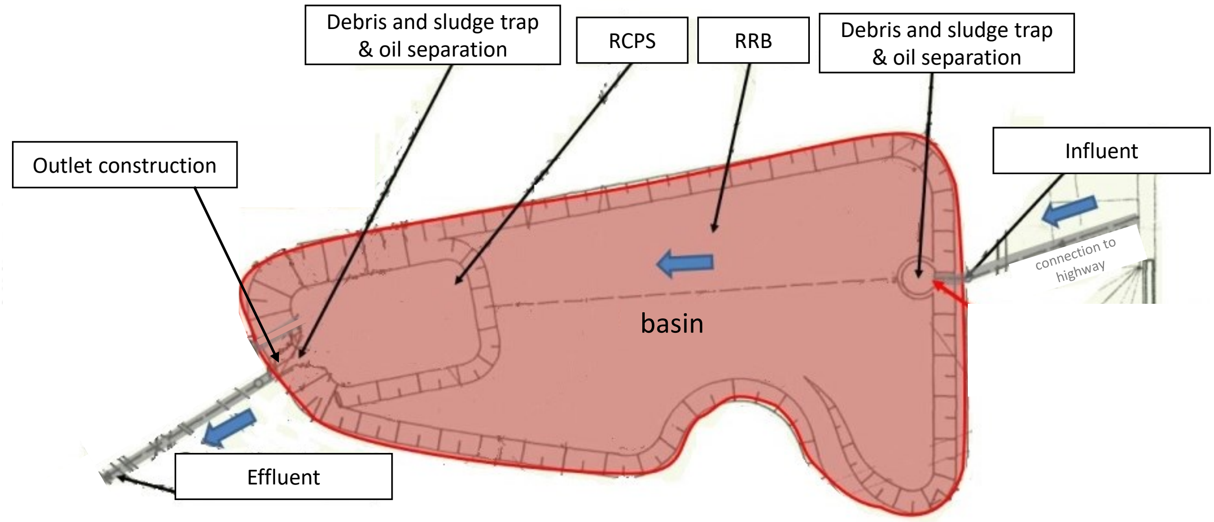


Figure 5: Scheme of a rainwater retention basin (RRB) and rainwater clarifier with permanent storage (RCPS).

The water present in the road basins is currently not **used** or **distributed** except for infiltration (in order to imitate the natural water cycle) or release to rivers, which, in broader sense, are also part of the natural water cycle. If the water is discharged into a river, there is a dosage defined level. Due to the treatment installed, a large part of the roadwater pollution is removed in advance. The remaining concentration is sufficiently low, so the standards for riverwater quality are not surpassed.

For **prevention** of water pollution there are no direct governmental measures. However, due to the climate crisis, a mobile shift from using cars to local public transport is supported i.e. with the governmentally partly granted “Deutschland-Ticket”, enabling people to use all local public transport vehicles all over Germany to a low price. There are so-called passenger parking spaces (P+M) near many junctions. They are used to form carpools, whereby the journey continues with only one vehicle. The concept, which has now been around for around 20 years, is very successful because the demand has increased significantly and thus, the spaces have now become too small almost everywhere. A truck toll is already in force since 2005 with many further additions during the past 20 years. Just in 2024 it has been expanded also for vehicles > 3.5 tons and thus lead to reduced DTV. This mobile shift could have a long-term effect on leaking of pollution from roadwater.

The applied measures of recycling water unable to seep on sealed road areas, result in benefits to the water cycle and thus the **ecosystem balance**. Also, the semi-natural retention basins can (temporarily) serve as a habitat for plants and animals.

2.3 France

Highways are defined by France's Roadway code as non-intersecting roads, accessible only at specially designated points and reserved for mechanically propelled vehicles (L122-1).

In France, roads could be classified regarding traffic, with a classification based on average annual daily traffic of vehicles per direction. Hereafter are considered as highways, roads infrastructures with significant traffic and two lanes per direction.

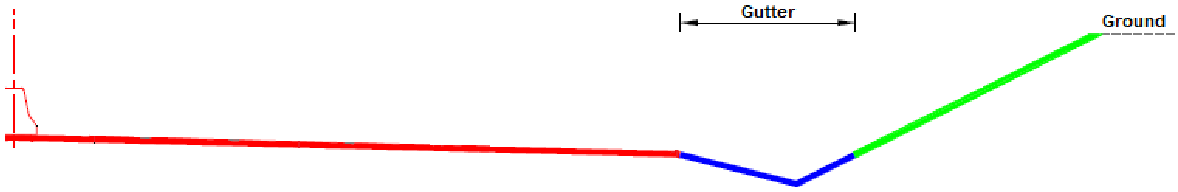
Historically road runoff water management main priorities are to ensure road users safety, avoid flooding risk increase (both for traffic keeping and people protection) and limit impact on receiving water bodies. Two guides were produced and largely used in France in the last decades for road runoff water management design ([1] and [2]).

[1] Roadway water management technical guide is from 2006, it can be found here (in english): https://doc.cerema.fr/Default/digital-viewer/c-17786

[2] Road Pollution Technical Guide from 2007 (in French): Pollution d'origine routière : Conception des ouvrages de traitement des eaux - Guide technique - Cerema

- Water quantity management

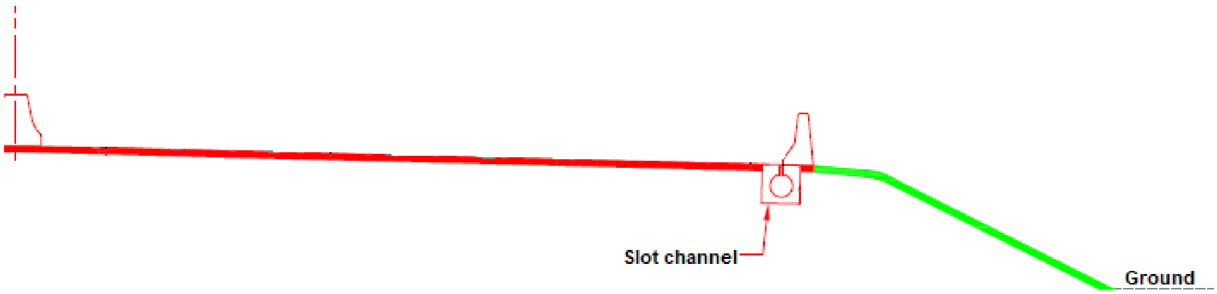
Design rules to evacuate rainfall are described in [1]. Historically road runoff water is managed with water collection network, leading to a centralized storage basin before a discharge to the environment (usually watercourses, but sometimes sewage or rainwater network). Ditches are often designed for decennial rainfalls. Gutters can also be used, as shown by the scheme below.



The use of grassed ditches is recommended for reasons of cost, also allowing roadway stormwater treatment. However, these structures can be concreted to limit infiltration where there is a risk of erosion or where groundwater is at stake (e.g. in the case of water catchments for drinking water).

When the highway is cut into the ground, the most commonly used structures are culverts or gutters with low slopes and depths for safety reasons. Those gutters are vegetated or concrete, depending on the vulnerability of the groundwater.

When the highway is embanked, since the 90s, rainwater is often kept at the crest of the embankment so it can be sent to a treatment and storage facility when crossing rivers. This is also useful to have enough of level difference to be able to discharged water into watercourses after treatment. The drainage structures commonly used are slot channel/gutters or rectangular gutters, as shown in the figure below.



Design rules to evacuate rainfall of highway and rural roads are described in a 2006 technical guide [1]. Historically road runoff water is managed with water collection network, leading to a centralized storage basin before a discharge to the environment (usually watercourses, but sometimes sewage or rainwater network). Ditches and gutters are often dimensioned for decennial rainfalls.

The infiltration of stormwater along existing highways could occur, and is becoming increasingly common for new road infrastructure projects, in particular those located near cities. Indeed, from 90's, stormwater management policies have strongly changed with switching from centralized to decentralized handling. They are more and more developed, for example by promoting Nature Based Solutions in the Water development and management master plans (Schéma Directeur d'Aménagement et de Gestion des Eaux, SDAGE). This is particularly the case for urban stormwater management but it also applies to roadwater runoff management with swales implementation for example.

Regarding flood risk prevention, transport infrastructure projects must not exacerbate flooding risk. This means limiting discharge rates to surface outlets (mainly watercourses but sometimes also sewage network), and sometimes the need of a temporary storage of water (usually requested for new highways). These stormwater retention targets are set out in planning and handling water documents such as Water development and management master plans (SDAGE) and others (PLUi, reglements d'assainissement etc). Local water authorities (Services départementaux de la Police de l'Eau) ensure this objective is met when examining the decalration or authorization files that must be submitted before the work is carried out.

Older freeways built before the 90s do not often respect these principles. However, stormwater retention can be imposed when roads upgrade (road widening, new interchanges, etc.).

Water basins are usually designed for 2- to 100-year return period rainfalls. The outlet discharge is defined by local authorities (a ratio of 2 l/s/ha in the north of France is commonly used).

- Water quality management

When designing highways, an analysis of the vulnerability of surface and groundwater must be carried out. Roadwater infrastructures and facilities must be designed by taking into account this vulnerability. In case of very strong water vulnerability, preventive measures are implemented to handle road pollution.

Regarding quality, runoff stormwater pollutants can come from several sources depending and related mainly to location characteristics, road itself and related equipments, traffic, vehicles and maintenance practices. These various sources lead to plenty of contaminants in various concentration. Pollution is usually characterized with global parameters (pH, COD, COT, TSS, THC…), inorganic compounds (heavy metals…) and organic compounds (PAHs, pesticides, PFOS…). Also emerging contaminants and microplastics should be investigated. Quality of stormwater runoff is highly variable : contaminants concentrations depend on location, rainfall events, prior dry weather periods, traffic, etc. Moreover fractionation (distribution between particular and dissolved phases) is depending on the pollutant and can evolve with time and environmental conditions such as pH, salinity, temperature…

For example, deicing salt use can lead to heavy metals compounds fractionation changes. This has consequences on pollutant treatment efficiencies. A synthesis of two French projects on road runoff water quality is done in a Bibliographic synthesis of research projects.

In a way of reducing pollutants emission related to road maintenance practices, please note that :

a) since 2014, national road maintenance services do not use weedkillers anymore,
b) during winter, maintenance teams try to use de-icing products (mainly salt) as little as possible. The use of salt in brine makes it possible to limit the quantities of salts spread on the traffic lanes.

Some pre-treatments and pollution control facilities for stormwater runoff from highways are described in Road Pollution Technical Guide from 2007 [2]. Some typical treatment facilities described are :

- grassed ditch,
- grassed containment reach,
- grassed subhorizontal ditch,
- treatment basin with dead volume,
- sanitary-type treatment basin (to avoid mosquitoes),
- sand filter (additional structure with a water treatment basin upstream).

Since storage is required, road basins are designed to remove part of the pollution :

- pre-treatment of chronic pollution by sedimentation by always having constant minimum water volume (dead volume),
- storage capacity for accidental pollution in dry or rainy weather, and waterproofing the basin to avoid infiltration of pollutants,
- taking into account the intervention time of the civil security services to close the basin.

The below figure shows a schematic diagram of a road treatment basin with dead volume

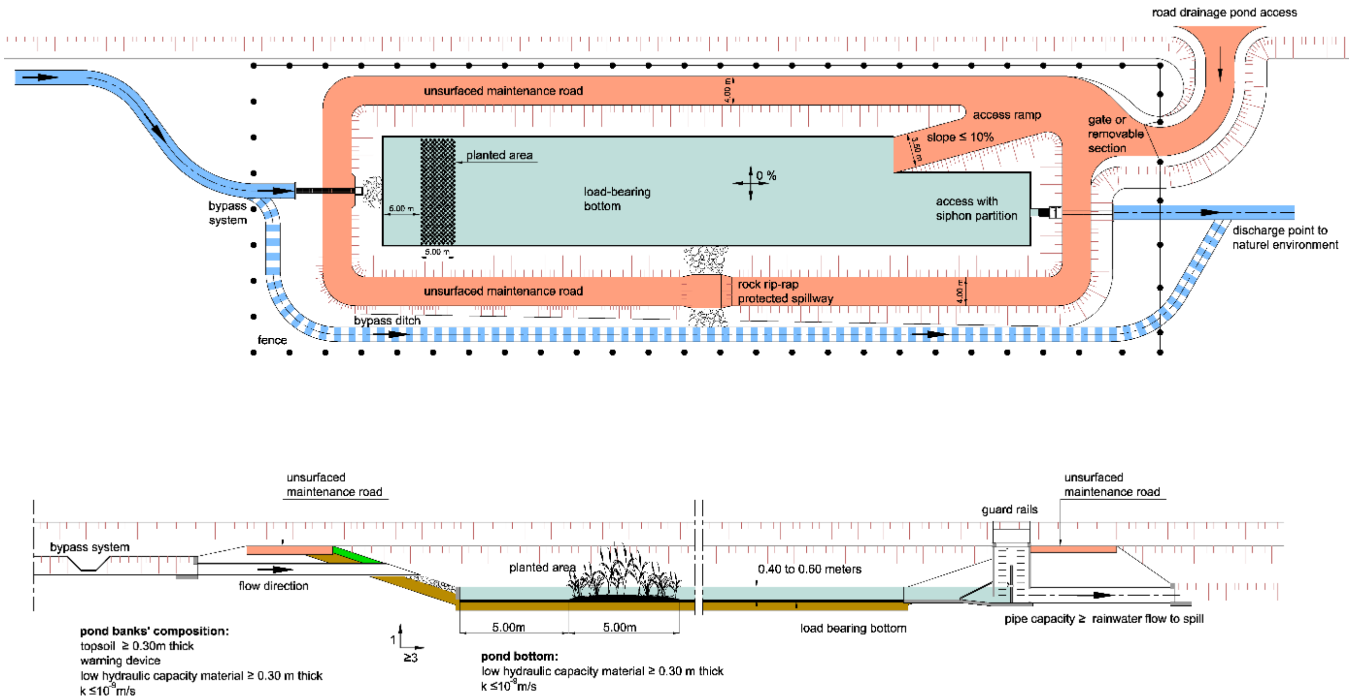


Figure 6: Schematic diagram of a road treatment basin with dead volume

Figure 7: Picture of a basin with dead volume (source: Cerema)

Several thousands of water basins were built in France since 1990. They must be maintained regularly to allow their effectiveness in time. For example, maintenance could involve mowing vegetation, checking basin waterproof membrane and settled sludge removal. Then sludge must be sent to treatment facilities adapted to its contamination level.

Typical waterproofed treatment basins cost about 200 to 400 €/m^3. But cost can be much higher for treatment ponds implementation for old highways or when underground basins are required.

For new highways or upgrading existing highways, infiltration is often requested by local water authorities, as required in built-up areas for new allotments, for example. However, this management of rainwater “at the source” must take into account the risks of accidental pollution and how to ensure that rainwater pollution is retained in the topsoil. Then removed soils must also be subjected to contamination measurements before handling.

In [2], pollution treatment facilities are designed on 2-year return period rainfalls. They are mainly designed to remove particular pollution, as based on natural settling or filtration and by having a dead volume.

Water resource protection structures designed in accordance of the recommendations of Road Pollution Technical Guide [2] are expected to have the following removal efficiencies (%), based on trends expressed in studies conducted by the French public works scientific and technical network in the 90's :

Pollution treatment structures	Abatement level (%)			
	TSS	COD	Cu, Cd, Zn	THC and PAH
Grassed ditch (min. length 100 m, no infiltration, zero slope)	65	50	65	50
Grassed containment reach	65	50	65	50
Grassed subhorizontal ditch	65	50	65	50
Sanitary-type road treatment basin	85	70	85	90
Sand filter	90	75	90	95
Road treatment basin with dead volume Vs* in m/h				
1	85	75	80	65
3	70	65	70	45
5	60	55	60	40

* V_S : settling velocity express : SS settle, when their falling velocity is ≥ Vs

It should be noted that rainwater storage structures with a permanent dead volume raise questions about mosquitoes, especially when they are located near urban areas. However, the initial investigations carried out on this subject on road basins in the north of France are reassuring.

In the aim of water reuse, it should be necessary to build additional downstream storage capacity of treated water.

As far as we know, water from road basins is not currently reused. The intended uses do not require a good physico-chemical and biological quality of the water: fire protection, cleaning of pipes... Restricted water users in case of drought such as car washes may be interested in this resource.

2.4 Netherlands

In the Netherlands, the primary responsibility for the management and maintenance of highways falls under Rijkswaterstaat (RWS). RWS manages approximately 5,600 km of highways, primarily consisting of multi-lane roads essential for national and international transport. For Rijkswaterstaat safety of the road users is the priority. In this regard, road water management is mainly done with a focus on safety of the road users. For example, puddles or standing water are considered dangerous and should not be able to form on the highway. Environmental concerns are taken into account in road water management too, but are of lesser importance than safety.

The main Objectives for RWS in roadwater management are as follows:

- Ensuring the safety of road users by preventing the formation of standing water (which can cause hydroplaning and other hazards).
- Protecting the quality of surface and groundwater from pollutants carried by road runoff.
- Complying with national and European environmental regulations regarding water quality and flood prevention.

Water management Strategies

For RWS. water management for highways is a critical component of road infrastructure planning, aimed at balancing safety, environmental protection, and compliance with regulatory standards. The country's flat topography and high population density make effective roadwater management essential to prevent flooding, protect water quality, and ensure road safety.

Integrated Framework for Roadwater Management: RWS employs a structured framework for managing road runoff, which is centered around four primary water management chains (routes). These chains are designed to handle various scenarios based on local soil conditions, road types, and environmental sensitivities.

Prioritization of Safety and Environmental Concerns: While safety is paramount, there is also a strong emphasis on minimizing environmental impact. Road runoff is managed to prevent pollutants, such as oil residues, heavy metals, and microplastics, from entering water bodies without adequate treatment.

Roadwater Management Chains

RWS uses a systematic approach to managing road runoff through a series of well-defined management chains, tailored to different environmental conditions and infrastructure needs. These chains ensure that road runoff is effectively collected, treated, and discharged, minimizing the impact on local water bodies and ecosystems. Each chain is designed to manage runoff based on factors such as soil type, proximity to surface water, and specific requirements of bridges, tunnels, and rest areas. By implementing these chains, RWS aims to maintain road safety, prevent flooding, and protect the quality of surface and groundwater in the Netherlands.

Chain 1 : Shoulder infiltration (preference)

This is the preferred road layout for Dutch highway design. The water draws to the edges of the road towards the shoulders, where it infiltrates. These shoulders are managed a bit, and need to be scraped every few years.

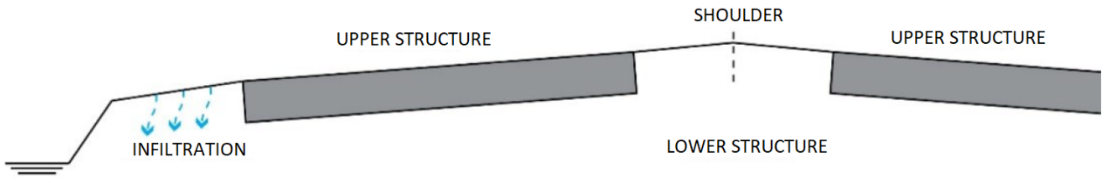


Figure 8: Chain 1 Netherlands; Shoulder infiltration (cross-section)

Chain 2: Deferred Roadside/Shoulder Infiltration

If soil infiltration isn't feasible, a sewerage solution with indirect discharge via specially designed infiltration facilities follows. These facilities don't connect directly to the regional surface water system. They only discharge road runoff to surface water under extreme weather conditions. Chain 2 consists of: sewerage, soil infiltration at the toe, soil passage, surface

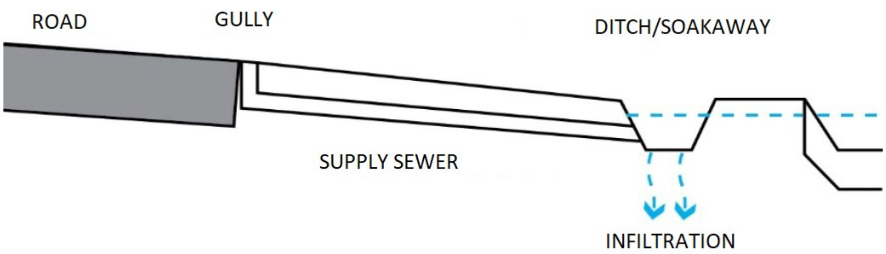


Figure 9: Chain 2 Netherlands; Deferred roadside/shoulder infiltration (cross-section)

water.

Chain 3: Direct discharge to Infiltration/Retention Facility

Bridge and tunnel water is ideally discharged indirectly via specialized infiltration/retention facilities at discharge points. For long bridges, direct discharge at intermediate supports to a designated surface water body may be necessary, which is environmentally acceptable due to the presence of a porous asphalt surface layer. Chain 3 includes: sewerage,

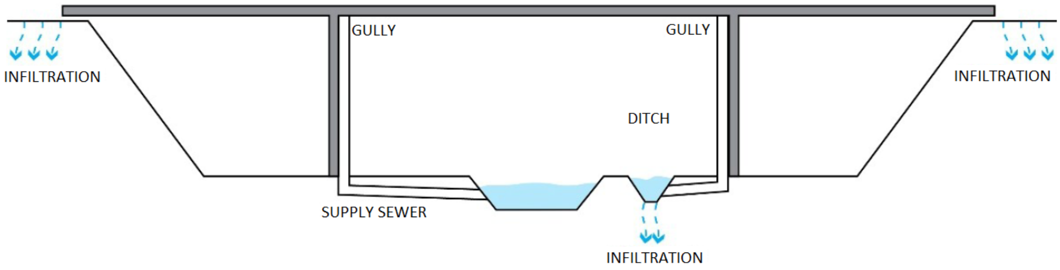


Figure 10: Chain 3 Netherlands; Direct discharge to infiltration/retention facility (cross-section)

infiltration/retention facility, surface water.

Chain 4: Rest Area

At rest areas, a closed asphalt or concrete surface is installed. Rainwater is drained through stormwater sewers to oil separators and then discharged indirectly into the receiving surface water. Chain 4 includes: sewerage, oil/dirt separator, infiltration/retention facility, surface water.

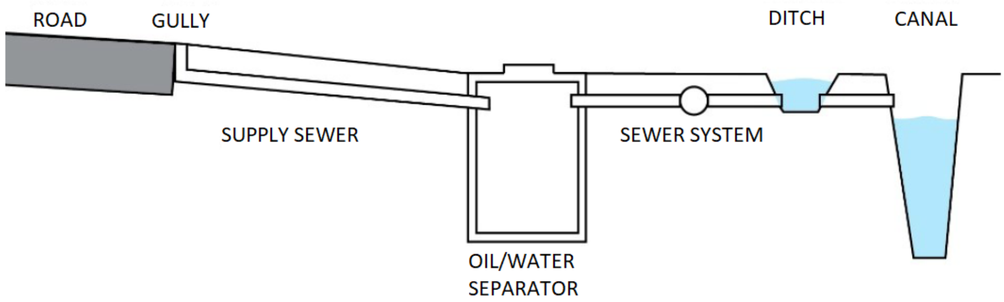


Figure 11: Chain 4 Netherlands; Rest area (cross-section)

Overview of Techniques and methods

Collection Techniques

The Dutch highway network employs various methods to collect road runoff, which is vital for preventing standing water and ensuring safe driving conditions. The primary method is roadside infiltration, allowing water to naturally seep into the soil along the road shoulders. The secondary method involves using gullies and manholes to gather surface runoff. In addition, the Netherlands makes extensive use of porous asphalt, known locally as ZOAB (Zeer Open Asfalt Beton). This specialized asphalt allows rainwater to percolate through the road surface, reducing runoff volume and helping prevent aquaplaning. By enabling water to drain through the asphalt itself and then flow to the side of the road, ZOAB acts as a small buffer, allowing water to spread more evenly and infiltrate gradually.

Treatment methods

Once collected, road runoff must be treated to mitigate environmental impacts before being discharged into surface or groundwater systems. In the Netherlands, treatment methods are adapted to the specific requirements of each location:

- Natural Infiltration: Wherever possible, the preferred treatment method is natural infiltration. This approach leverages the existing soil to filter out contaminants as water is allowed to percolate gradually back into the ground.
- Oil Separation: In areas where natural infiltration is not sufficient due to soil conditions, high groundwater levels, or the presence of sensitive environments, additional treatment facilities are used. This primarily is the case in resting areas. Collected runoff is directed through oil separators that remove hydrocarbons.

Storage Techniques

There is not a primary focus on storage when it comes to roadwater management in the Netherlands. Instead, the emphasis is placed on effective infiltration and the direct discharge of runoff into the surrounding water systems. The country's approach for the last decades prioritizes natural infiltration wherever possible, ensuring that water is absorbed into the soil along roadsides or directed to designed infiltration facilities. In situations where infiltration is not feasible, such as in urban areas with high groundwater levels or impermeable soils, runoff is discharged into local water bodies following basic or no treatment.

While storage is not the main strategy, certain techniques are employed in specific cases to manage peak runoff volumes. One such technique is the (relatively limited) use of retention basins. These are used to temporarily store road runoff, especially during heavy rainfall events, primarily at the center points of cloverleaf intersections ('klaverbladen'). These basins help manage the flow and allow controlled discharge of water, preventing flooding and reducing the pressure on local drainage systems. However, these are not widespread solutions and are implemented primarily in locations where immediate infiltration or discharge is not viable

Distribution, Use and other benefits

Currently, there is no significant focus on the reuse of roadwater, and as a result, there is no dedicated distribution system for roadwater utilization. In some instances, retention basins located in cloverleaf intersections have attracted wildlife, providing temporary habitats and contributing modestly to local biodiversity. However, such occurrences are minimal, and the use of roadwater for broader ecological or utility purposes remains limited.

2.5 Flanders

The Agency for Roads and Traffic Flanders (AWV) is responsible for the main roads in Flanders. Municipalities only advise via the transport regions. For AWV safety of the road users is the priority. In this regard, road water management is mainly done with **a focus on safety of the road users**. However, the presence of a road means a large area of paving. Rainwater can no longer locally infiltrate and is discharged into canals or into the sewer system at an accelerated rate. This can not only cause local flooding during heavy rainfall, but also cause increased water pressure downstream on the water system. And might not be desirable in periods of drought. More than 16% of Flanders' surface is paved, of which more than 18% is due to transport infrastructure. That is more than 5 kilometres of road per square kilometre.

The way this type of roads are build is described in a technical **vademecum (Europese hoofdwegen)** that is **binding between the Flemish agency and the contractor**. Another **vademecum (natuurtechniek)** has been developed for nature-based techniques, which wants to serve as a **guideline** for contractors in how to better fit in the roads within its natural environment, but is of less binding nature. This can tackle drainage and ways to defragment the natural habitats they are crossing. Standard, for a good drainage of stormwater a slope of minimum 2,5 % is foreseen next to the road, mostly 5 %. When the road is more than 18 m large, a splitted profile for drainage is needed. Water planning in any case should be avoided (water layer thicknesses of 2 to 3 mm). In the first place the roads are designed for safe use. In theory, and by preference drainage occurs by infiltration next to the road, or by free passage to the side into an open ditch. Drainage can also take place via gutters and gullies with connecting pipes or slope gutters directly on the roadside ditches. However, such a drainage system will not always be possible, for example when the roadway drains to a central reservation that is not obstacle-free. In such situations, a drainage system must be realized consisting of longitudinal channels, gullies and sewers. **The design of the drainage system must be made on the basis of the *"Code van goede praktijk voor het ontwerp de aanleg en het onderhoud van rioleringssystemen"*.**

So there are rules that define the amount of drainage needed from the roads to ensure safety, and rules that define how stormwater, if unavoidable, can be connected to the sewer system.

→ Rules for safety that define the volumes that needs be drained are:

Measureable rainfall intensity: 100 l/s/ha - Measureable rainfall duration: 5 minutes - Water layer thickness: maximum 2 to 3 mm - Puddle length: maximum approximately 10 m in one of the ruts

→ Rules that define the amount that can be connected to the sewer system (last step):

Regarding stormwater, on the public domain, priority is given to infiltration then above-ground delayed drainage via canals and finally upward buffering. This fulfils the principle of 'retention-buffering-discharge' and can only move on to the next step (gullies, pipes and gutters) only if the previous one is technically not possible. See Ladder van Lansink.

It is **prohibited to construct infiltration facilities in protection zones for groundwater extraction type I or II to minimize the risks of contamination of our drinking water wells**. Outside the drinking water protection zones, it is technically (if the soil type allows it) certainly no problem to infiltrate non-contaminated rainwater into the soil.

If it turns out that keeping rainwater on site via infiltration is not feasible, a choice can be made for disposal of stormwater after buffering. The purpose of extending local buffering is to top of the peak flow in the downstream water system. Maintenance practice has shown that the flowthrough discharge of a buffering system should not be smaller 20 l/s for the public domain.

The ditches are also by preference above ground and form separate infiltration units (buffering, not merely draining). At least at the level of these hydraulic structures, the ability to discharge peak flow corresponding to the return period for which local flooding should not occur.

Even if optimal use is made of source oriented measures (infiltration), a drainage system to the sewers may still be necessary. When separated piping system for rain water and grey water is not installed at the public domain, both flows will arrive in one mixed sewer system. A careful design in this case is needed, where precautions need to be taken, so the overflow event of this mixed systems to the watercourse is limited, from a qualitative and quantitive point of view.

The following rules are adopted for the overflow system: highly sensitive watercourses: once every 10 years; vulnerable watercourses: a maximum of 7 times a year, strategically important watercourses: max 10 times per year; others: no standard. Although site specific more strict criteria can be defined by request during the permit process (i.e. when a Natura 2000 site, because of flooding, …) when motivated.

In reality, from the water manager point of view, we mostly see gutters, concrete ditches, sometimes a buffer basin and (accelerated) drainage towards the water course and/or nature area's (Fig.).

Figure 12: Left: Overview of locations investigated around the ring of Brussels, E40 and E411 in the Dyle-Senne river basin where water arrived either directly, or via a buffer basin in the rivers. We also monitored the efficiency of one semi-natural water treatment near the E40 in Bertem; and one more technical oil-seprating sand filtration system near Brussels (Leonard); Right: illustrating the different ways of road water entering the watercourses in the Dyle-Senne basin

For the « older » roads the information is only available in old plans and it is not clear how well the maintenance for basins is. To our knowledge **we miss an overview of the different types of drainage and buffer systems along the (main) roads.**

No further obligations are made with respect to water quality of the water that is being discharged. But in reality we do so see that there is an impact on the ecosystem, the watercourse, from our monitoring upstream and downstream from such a discharge point in the IJse valley. Furthermore, large part of the pollution is kept in the sediment, which is often considered the memory of the system.

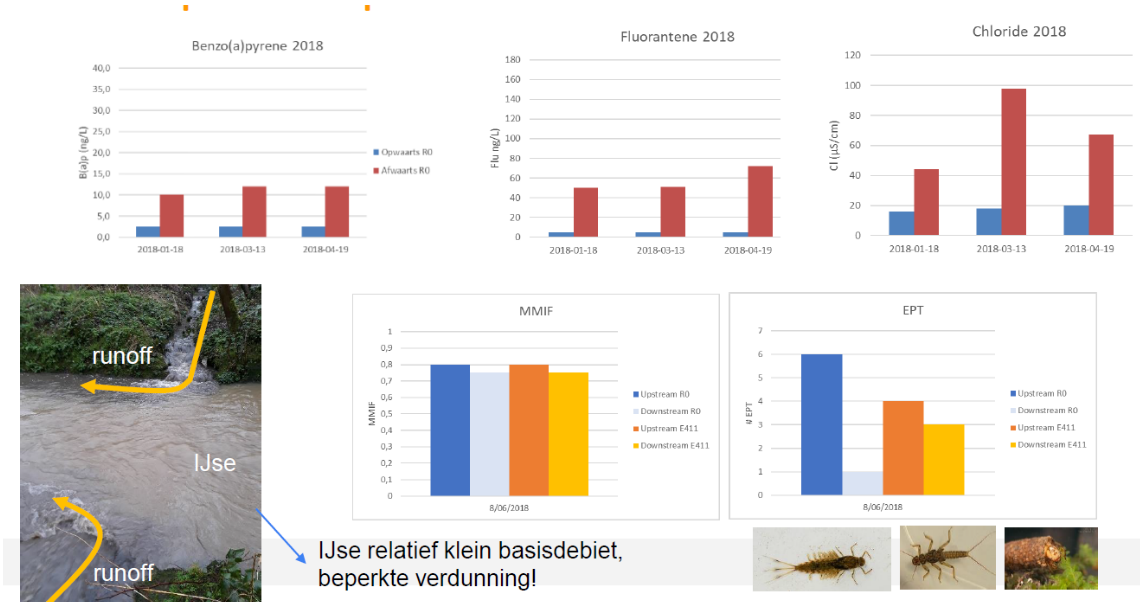


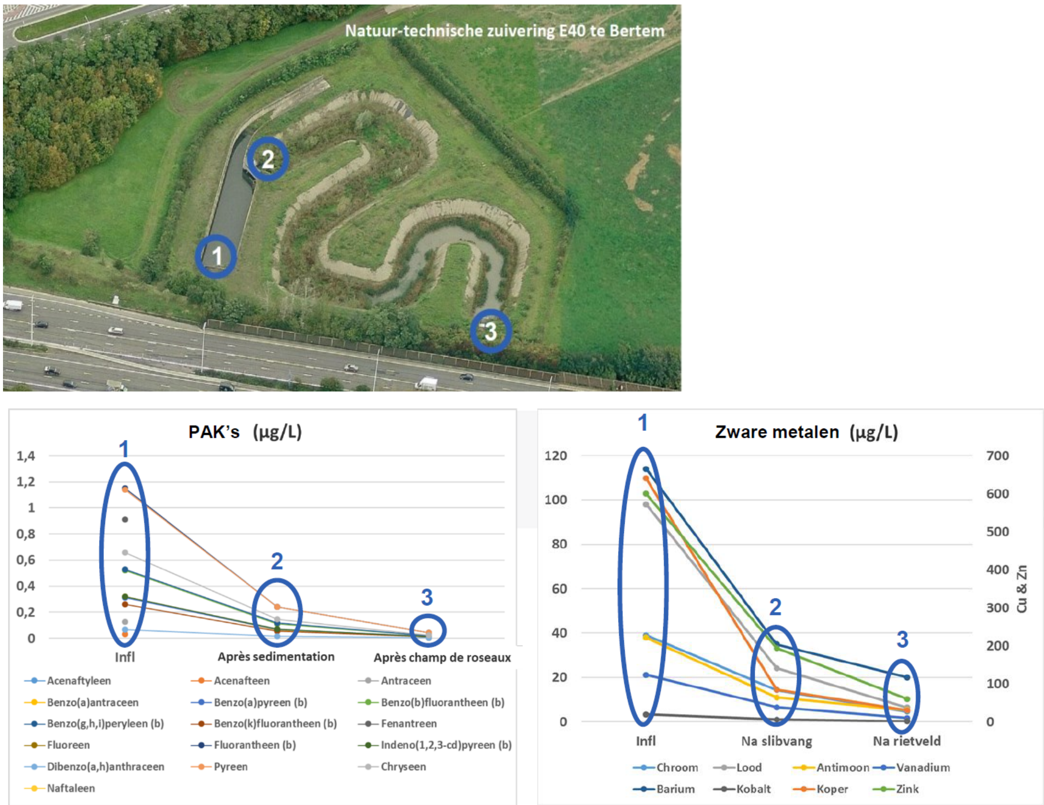
Figure 13: Showing the impact on PAH, and biology indices upstream and downstream the point of inflow with runoff from the E411 on the IJse (tributary of the Dyle). Depending on the receiving volume of the river, it will have either a high or relatively low impact.

With the renewed Urban Waste Water Treatment Directive and the new Stormwater decree, **rules become more strict towards the environment with respect to the *prevention of overflow systems*** and to *increase infiltration*. The decoupling of rainwater from mixed sewers is more and more a reflex that is being made. This implies more road water might be decoupled and will be brought directly or indirectly to the water courses and/or natural environment. Therefore de Vlaamse Milieumaatschappij conducted a study in LIFE Belini that (1): characterizes the chemical composition from runoff from road water and (2) that made recommendations on how to ensure a minimal impact on the water course (indirect by roadside infiltration, direct by water treatment systems).

We see that i**n new projects of road renovation, the shift to infiltration next to the road side** is more often made nowadays (cf. Complex North South project Limburg). When this is not possible other systems are considered (collecting, treating by sedimentation basin and infiltration bed).

At this moment, we only have ***ad hoc* examples** of pilot cases **for treatment** of road water and there is no general approach that is applied (i.e. pilot in Bertem and Leonard).

I.e. we monitored the semi-natural water treatment system in Bertem, which receives water from the E40 and discharges it into the Voer, a tributary from the Dyle. Here we used an autosampler trying to catch the first flush from the road. About 10 samples during a period of three months in 2019 were taken. The results and exchange of them with our colleagues in Brussels in LIFE Belini learnt us, that especially the number of "dry days" prior to the run off event are important in defining the runoff water quality composition. The outflow sampled indicates the removal efficiency of the system in place (less frequently sampled).



- 5 naar 2 overschrijdingen van JG-MKN
- 77 % na slibvang
- 95 % na rietveld

- 7 naar GEEN overschrijdingen van JG-MKN
- 72 % na slibvang
- 92 % na rietveld

Onderhoudsvriendelijk!

Figure 14: Up: semi-natural water treatment of road water run off in Bertem; down: treatment evaluation

i.e. we also monitored the technical water treatment system existing at Leonard, at the crossing of the E411 and Ring around Brussels. We found the treatment mostly removes sand, but the smaller particles are not removed, but flushed to the above ground pond thereafter. Also the efficiency depends on maintenance, which is often indicated as a bottle neck. Recommendations were formulated to improve the removal efficiency of the pollution related to the suspended sediment particles.

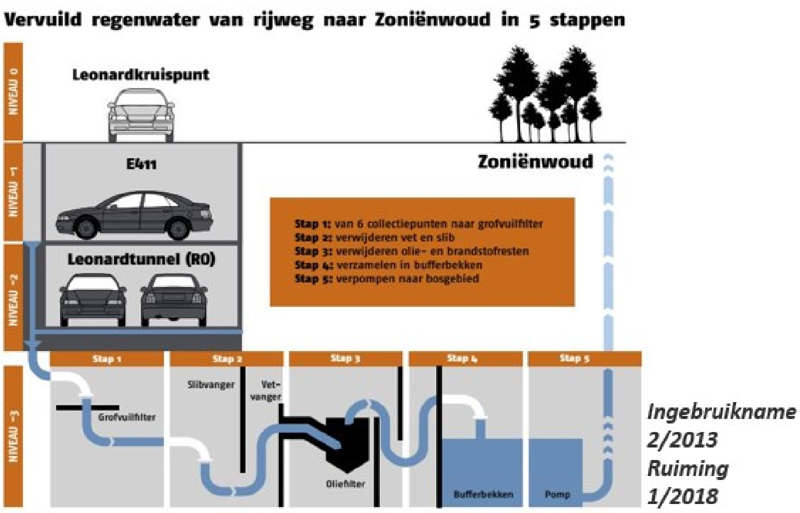


Figure 15: Technical water treatment system beneath the Leonard crossroad tunnel system receiving the runoff water from both the E411 and R0.

In 2025 AWV (Flanders Road Administration) will install together with ANB Agency for Forestry and Nature) and the province of Vlaams-Brabant (water manager of the IJse river at that location and another partner in Belini) a semi-natural water treatment system at the Koningsvijvers reducing the impact from runoff water from the ring of Brussels on the Sonien forest (Natura 2000) and the source of the Ijse river (priority for Flanders for the Water Framework Directive). The technical design from the study bureau was coordinated by the Vlaamse Milieumaatschappij in LIFE Belini; and we will foresee a further follow-up and monitoring of the system once in place. Furthermore, VMM is currently also involved in coordination of a solution at other locations on the IJse river (Frans Verbeekstraat, Esdoornenlaan, Moerlaenbeek) in close cooperation with AWV.

Also for re-use only *ad hoc* experiments exist in the framework of circular water projects (i.e. B-WaterSmart Living Lab project Mechelen, case in Hombeek were stormwater is reused; Sander Bombeke from proefstation voor de groenteteelt) .

Figure 16: On the use case for re-use of stormwater, not the same as runoff water from roads.

Challenges in re-use for Flanders are described by the "Uitdagingenbundel". The document is dynamic: challenges, priorities and solutions provided by actors can be added to it. Every six months, the document is updated with the latest contributions.

2.6 General information on highways in the four partner countries

How to deal with water runoff from roads depends largely on context. The context in each country might be slightly different. Therefore, some input on main characteristics for roads was gathered from all participating countries in Table 1. This overview shows also how roads are characterized might be different. Furthermore, also differences in climate can induce differences in supply and needs in the respective countries. Not all countries were able to retrieve all information. Clearly the road management is organized with different organizational settings.

In Germany, the national "Autobahn GmbH" is responsible for federal highway (2-6 lane motorways) management all over the country, whereas the responsibility of local road (1-2 lane roads) management is divided over the federal states, cities and municipalities.

In France, the management of roads seems to be divided between the Ministry, departments and municipalities, and a higher department level of water manager is involved in setting the legal framework.

In Flanders, road management is organized at a regional level and locally at the level of municipalities. The regional level defines the overall legal framework, however through project-level permits, this depends on the water authority having jurisdiction, for advice (first category non-navigable, second category…).

In the Netherlands, another type of asphalt is used, which may cause the largest impact on a different setting and context.

Another remarkable difference are the different legal approaches that have been chosen in the different countries, which will be further investigated in Activity 2.

This table is non-exhaustive. Some aspects that may also be important are not included in this table, for instance the type of asphalt (porous or non-porous build up → ZOAB vs DAB resp.), the road maintenance frequency, etc.

Table 1 General information on highways in the four partner countries

	Germany	France	Netherlands	Flanders
Road manager for main roads (highways)	Autobahn GmbH des Bundes (Federal highways)	Ministère de la transition écologique et de la cohesion des territoires.	Rijkswaterstaat RWS	AWV
Other road managers (local roads)	Each federal state has a different one for federal roads and state roads; in addition cities or communities	Departments, Metropoles and Communes.	Municipal level and provincial level	Municipalities
Water manager (for first category non-navigable waterways)	Local lower water authority	DDT (departmental directorate of territories)	Waterschappen	VMM
Km of main road at national authority level (can be 2-6 lane* motorway)	13.200 km (federal highways, “Autobahn, BAB”) with a total lane length of 59.000 km (average of 4.5 lanes per highway kilometer/ 2-3 lanes in each direction)	11.700 km (state highways) (2017) 9.200 km conceded The national authority is also managing 9.500 km of national roads.	5.571 KM (federal highways) (2022)	7.000 km main and primary roads (A or E-numbers), beltways (R-roads) and large part of secondary regional roads (N-roads)
Km of roads at national authority level (can be 1-2 lane roads)	38.000 km Bundesstraßen (B roads): most have 1 lane in each direction: 76.000 km total lane length 87.000 km Landstraßen (L roads): most have 1 lane in each direction: 174.000 km total lane length 92.000 km “Kreisstraßen”: most have 1 lane in each direction: 184.000 km total lane length All not managed by the Autobahn GmbH total lane length 434.000 km			About 61.000 km of local roads in Flanders are managed by municipalities
KM driven on highway/year Road use intensity ?	Depending on location of highway: minimum 2.000 to maximum of 240.000 vehicles/day (DTV daily traffic of vehicles)		69.3 billion KM/year (2023)	For heavily used highways about 50.000 to 70.000 vehicles per day on average for 2023; on the ringways it can increase up to 100.000
% of highway kilometers at national authority level	6 % total length, 14 % total lane length	95 %	96 %	100 % when compared to the regional level. When comparing to the national level, taking into account Brussels and the Walloon region, AWV manages for Flanders about 44 % of the main primary and regional road network

	Germany	France	Netherlands	Flanders
Weather conditions (annual average rainfall 2016-2021)	Bundeslandweite Mittelwerte: NRW, Bayern, Ba-Wü			134,6 mm = monthly average in Ukkel (2016-2020) - *considered as higher according to previous observations (measurements since 1981)*
De-icing strategy	Salt (NaCl-Solution)	"Wet salt": mix of CaCl2 & NaCl solutions. Sometimes only NaCl		Salt (NaCl) 70 dry / 30 brine; only if temperatures fall really low (below -7°C; CaCl2 is used)
Accidents (with trucks spilling?)				In total 104 accidents with oil identified in 2021impacting the first category rivers from VMM. About half of them are related to spills of heating oil (mazout). A seperate category is not been made, but looking into the description of the incidents we estimate about 30 % related to accidents with traffic and oil spill.
Overall road water management strategy	Collection and treatment and recycling to nature	Collection and treatment?	Infiltration and treatment by topsoil removal?	Collection, no treatment
Road water – quantitative rules	Individual (local) Lower water authority	Police of water on departmental level. Temporary storage is requested for runoff from roads.	No, it has been decided not to legally prescribe a national policy line for runoff from national and provincial roads. The relevant road authorities are required, with the help of the legal duty of care, to determine how to deal with runoff from roads	Yes, Stormwater decree, Code van goede praktijk Riolering, Environmental permit - Watertoets
Road water – qualitative rules	Ordinance on requirements for the discharge of waste water into water bodies (Wastewater Ordinance, AbwV); local lower water authority (local=place of discharge or drainage), in addition often depending on the designation of a groundwater protection zone.	Must not aggravate the quality of water bodies. Water vulnerability is determined to decide of protective measures needed.	No, it has been decided not to legally prescribe a national policy line for runoff from national and provincial roads. The relevant road authorities are required, with the help of the legal duty of care, to determine how to deal with runoff from roads	No (stormwater considered as clean)

3 Digital Approaches to Balance Demand and Supply Side

3.1 Inventory of existing digital initiatives in partner regions

This table presents a range of digital initiatives related to balancing water demand and supply, highlighting current approaches and technologies in water management. These initiatives help showcase how data-driven methods, such as real-time monitoring, predictive analytics, and IoT integration, are used to optimize water distribution, reduce waste, and improve resource allocation.

Table 2: Digital initiatives related to balancing water demand and supply

Vlaamse Smart Data Space	A platform promoting secure, decentralized data sharing in Flanders, focusing on creating open ecosystems through standardized data integration for various sectors, including water management.	https://www.vlaanderen.be/vlaamse-smart-data-space-portaal
Internet of Water Flanders	A platform promoting secure, decentralized data sharing in Flanders, focusing on creating open ecosystems through standardized data integration for various sectors, including water management.	https://www.imec.be/nl/vlaamse-innovatiemotor/samenwerking/vlaamse-onderzoeksprogrammas/internet-of-water-flanders
WaterRadar	An online platform that provides real-time water level and flood data across Flanders, supporting emergency planning and response.	https://waterradar.be/#/map
WaterAtlas	A comprehensive data platform offering various maps and datasets related to water in Flanders, aiding in water management and policy planning.	https://www.wateratlas.be/
WaterBarometer	A tool for assessing and benchmarking water use efficiency and sustainability across different sectors in Flanders.	https://www.waterbarometer.be/login
Aquamarkt	A marketplace for water reuse, specifically focusing on the potential for effluent reuse, including water quality data and exchange possibilities.	https://www.aquamarkt.be/pages/effluent#effluentpotentieel
VLAIO Water Data Market Consultation	A consultation process for stakeholders involved in water data management and sharing, aiming to refine the use of water data in Flanders.	https://www.vlaio.be/nl/events/marktconsultatie-waterdata-240619
CIW Water Data Working Group	A working group focused on integrating water data management across Flanders, emphasizing collaboration and data sharing among stakeholders.	https://www.integraalwaterbeleid.be/nl/kalender/ciw-vwds_klankbordgroep-v0-01-1.pdf
TZW Digital Solutions – Water demand forecast	An example of a digital service for forecasting short-term water demand based on a transparent machine learning model, used by water supply companies.	https://tzw.de/en/solutions/digitalisation#:~:text=Water%20demand%20forecast

3.2 Data spaces and their relevancy for Climate Adaptive Water Hubs

Data spaces are frameworks that allow multiple stakeholders to securely share and collaborate on data while maintaining control over their own information. Key concepts like data sovereignty, interoperability, scalability, and collaborative innovation are at the heart of this approach. These concepts enable seamless, flexible, and trusted data exchange, which can be critical for projects like Climate Adaptive Waterhubs (CAWH), where diverse parties - road authorities, drinking water companies, nature organizations, citizens, and industries - collaborate on managing water resources, including roadwater run-off, in innovative ways.

Data sovereignty is central to dataspaces, ensuring that each stakeholder retains full control over their own data while selectively sharing it with others. In a CAWH setting, road authorities might share infrastructure data, while drinking water companies provide water quality metrics, all without losing ownership of their sensitive information. This fosters trust, enabling stakeholders to collaborate freely while safeguarding their data's privacy and security.

Interoperability is another key advantage of dataspaces, enabling diverse systems and data formats to work together seamlessly. Each stakeholder in CAWH may use different data types - geospatial data for roadwater flow, purification data from water companies, environmental impact reports from nature organizations - yet a dataspace allows all these formats to integrate and communicate effectively. This ensures that stakeholders can easily access and use each other's data, facilitating informed decision-making and coordinated actions, such as improving water storage or treatment.

A significant benefit of dataspaces is **scalability**, which allows systems to expand and evolve as needed. In a dynamic context such as climate adaptation, water demand and supply will shift over time, and the CAWH project will need to incorporate new data streams, stakeholders, and technologies. A dataspace is designed to accommodate such changes without disruption, allowing new participants—like local governments, researchers, or tech providers—to join the platform and contribute data as the project grows and the water challenges become more complex.

Finally, **collaborative innovation** thrives in a dataspace environment, where stakeholders can share their unique data to co-create new solutions. For example, nature organizations could use real-time roadwater run-off data from road authorities to develop green infrastructure like bioswales, while water companies could analyze combined datasets to improve purification techniques for treated roadwater. The ability to cross-reference and collaboratively analyze these data sources enables innovative approaches to water management that would be difficult to achieve in isolation.

By incorporating data sovereignty, interoperability, scalability, and collaborative innovation, dataspaces empower CAWH stakeholders to securely share, integrate, and build upon their data, resulting in more resilient, adaptive, and innovative water management strategies in the face of climate change.

3.3 Bottom-up data space design framework

This chapter proposes a bottom-up methodology for designing such data spaces, focusing on local needs and stakeholder collaboration. This approach enables responsive, community-centered infrastructure that leverages shared data to enhance water resilience within transportation networks.

Despite substantial documentation on data space conceptualization, there is still a lack of clarity around how to support stakeholders in making informed decisions about participating in these spaces, often reducing their willingness to share data. To address this gap, imec is conducting research to introduce a bottom-up framework for data space design. This framework offers tools to identify and tailor data space capabilities to diverse use cases. Although initially created within an urban mobility context, the framework is domain- and technology-agnostic, making it adaptable for other sectors, such as water management.

The framework is intended to serve as a practical tool for the initial stages of co-creating data spaces. It supports two distinct development processes as outlined by the Data Spaces Support Centre (DSSC, 2024[1]):

1. The process that identifies and describes individual use cases in detail to clarify the benefits for the data space participants and identifies the data space's functional requirements.
2. The process that translates the functional requirements into a useful data space design.

The two key components of the proposed framework align with the two development processes, i.e., the intake canvas can be used for the first process, and the capability mapping for the second process.

Intake canvas

The intake canvas is the initial step in the data space design framework, following a bottom-up approach to gather detailed information on various use cases. The core concept of the canvas is the "data product offering" (DPO), as defined by the DSSC[2]. A DPO provides potential users with all essential information about a data product, including its structure, access details, rights, and responsibilities. This helps data consumers decide if the data product fits their needs and facilitates the arrangement of any usage agreements.

The intake canvas is divided into three main sections—business, technical, and governance—reflecting the DPO's structure. Drawing on concepts from the DSSC Blueprint v1.0 and the Open Data Product Specification (ODPS), the canvas aligns with data initiatives and employs a comprehensive metadata model. This model includes key technical, business, legal, and ethical aspects essential for data marketplaces and the broader data economy.

Data space capability mapping

The second pillar of the data space design framework is the capability mapping, which connects questions from the intake canvas to specific technical capabilities within the data space. This uses the capability-driven design (CDD) approach by Berziša et al. (2015)[3], where a "capability" is the capacity that enables an enterprise to meet a business goal within a specific context. CDD's flexibility allows the system to adapt if the business goals or application contexts shift, which is often necessary given the lengthy timelines for data space development.

In this framework, information from the intake canvas regarding business goals and contexts is mapped to technical data space capabilities. These capabilities are aligned with the DSSC Blueprint v1.0's functionalities but are reorganized to support the CDD method, ensuring the data space can dynamically respond to evolving needs. This approach follows DSSC guidelines, which recognize that flexible capability clustering can enhance adaptability in data space architectures.

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[1] Data Spaces Support Centre. (2024, March 11). Data Spaces Blueprint v1.0. https://dssc.eu/space/BVE/357073006/Data+Spaces+Blueprint+v1.0

[2] Data Spaces Support Centre. (2024, March 11). Data Spaces Blueprint v1.0. https://dssc.eu/space/BVE/357073200/Conceptual+Model+-+Data+Products+and+Offerings

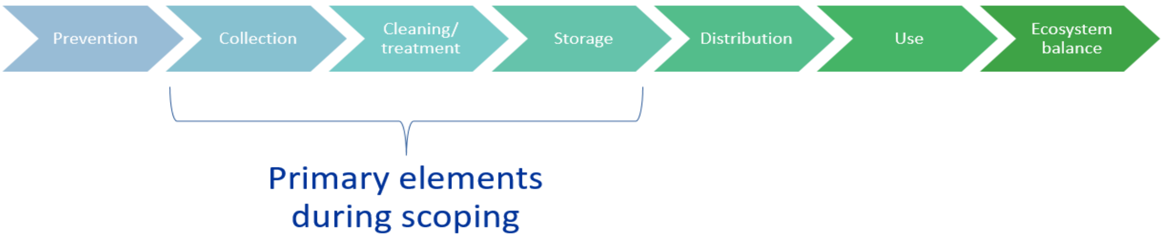
[3] Bērziša, S., Bravos, G., Gonzalez, T.C. et al. Capability Driven Development: An Approach to Designing Digital Enterprises. Bus Inf Syst Eng 57, 15–25 (2015). https://doi.org/10.1007/s12599-014-0362-0

The proposed bottom-up methodology offers a foundation for future activities in Climate Adaptive Water Hubs (CAWH), particularly by fostering scalable, adaptable data-sharing frameworks that evolve alongside climate and infrastructure needs. This methodology also serves as a logical progression of existing stakeholder engagement initiatives, encouraging continuous feedback loops. Consequently, it not only supports water demand and supply balancing use cases but also helps establish a resilient, stakeholder-driven model that can adapt to changing circumstances and infrastructural shifts.

4 Survey on Roadwater management

4.1 Introduction and description of the survey

The aim of the survey was to gather more information on current practices in the management of roadwater and to learn from inspiring experiences. As a basis for the survey we were looking for elements concerning the contribution of roadwater management to climate change mitigation. We derived these elements firstly from analysing existing practices on roadwatermanagement, i.e. the technologies of collection and use of runoff water and the technical state of the art in road/highway infrastructure technology (as described in chapter 2).



In this process 7 elements were identified for a balanced roadwater management to face the challenges of climate change. See Table 3. Combined in one location they make a local water system we called Climate Adaptive Waterhubs.

Table 3: Definitions of the 7 elements of climate adaptive water hubs as used in the survey.

element	definition
Prevention	With prevention we are talking about how to prevent pollution linked to roads (by traffic and infrastructure) to be directed to the water system (e.g. groundwater, rivers). This can be both legislation or technical innovation
Collection	With collection we are talking about the way roadwater is directed after leaving the road/pavement before it is either infiltrated, cleaned, stored, distributed, or used.
Cleaning / Treatment	With cleaning we are talking about any treatment method before the collected roadwater is further distributed/re-used/infiltrated. Techniques are classified as natural, semi-natural and technical solutions and can be either centralized, partially centralized or decentralized.
Storage	With storage we imply means to store water for after collection. It can happen both before or after cleaning, and before distribution and re-use.
Distribution	With distribution we imply means to deliver (clean) water to possible uses or users with the purpose of re-using it
Use / Re-use	With use we refer to ways that cleaned roadwater is being (re-)used
Ecosytem balance	With ecosystem balance we imply the way that clean and infiltrated water/stored roadwater can give positive effects to the natural ecosystem as another “user”; now and in the future (taking into account that more extreme weather events of rainfall and drought will occur because of climate change)

The survey was built along the 7 elements to gather knowledge and define knowledge gaps. Primary elements expected during scoping concern the practices to collect water alongside the highways, the cleaning and treatment processes in place and existing water storage facilities. In addition to the 7 elements of a climate adaptive water hub, the analysis reviews questions concerning legal frameworks & boundaries and potential IT solutions asked to the respondents.

The survey was online open on the rural roadwater rescue website to the general public from July to the beginning of October 2024. In order to have as much answers as possible, partners asked people working in this field to participate to the survey: other associated partners, experts and specialists, road network operators, national and local authorities…The survey was based on a questionnaire in English drawn up by the project partners. A translation of the survey in Dutch, French and German was also provided to help people less familiar with English language.

There were 21 responses in total to the survey. The answers are mainly analyzed with one paragraph per element.

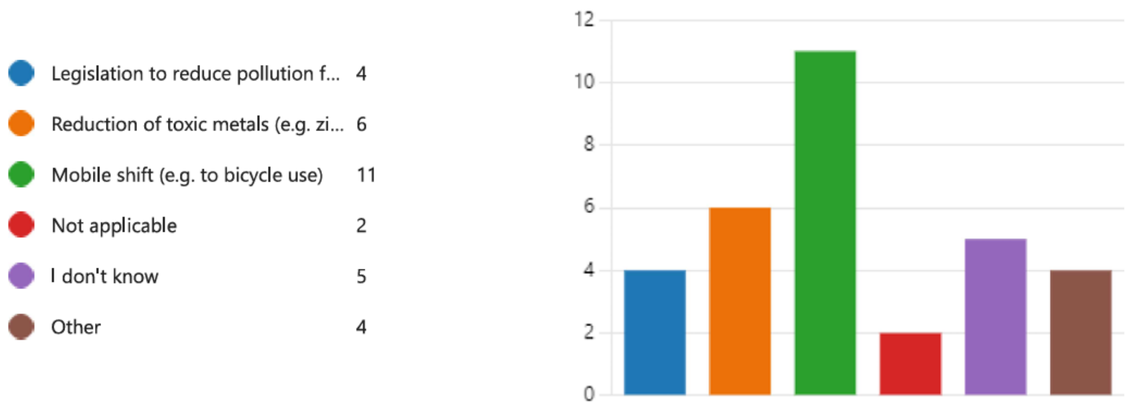
Partner Data Collection

Parallel to the RRR survey partner data was collected during the process of submitting a next call for INTERREG NWE (called STEREO ROADS) a.o. based on RRR. Data collected includes almost 50 previous and ca. 20 parallel projects related to roadwater management, as well as relevant policy information. Where relevant this information was added. However, this partner data collection (PDC) was not analysed deeply enough to be able to address it to the elements used in this report. But It can be used for upcoming project activities of RRR, e.g. solutions and legal boundaries. The raw survey data is shown in excel-documents on rural-roadwater-rescue.nweurope.eu .

4.2 Results of the survey

4.2.1 Prevention

21. Which efforts are undertaken in your country to prevent (leakage of) roadwater pollution? Multiple answers are possible.



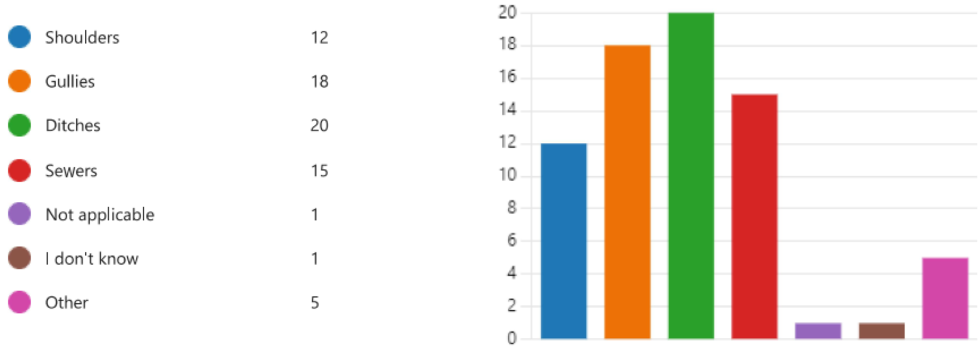
- We want a maximum of 50% of all passenger transport journeys to be made by car and for people to optain for sustainable alternatives and collective transport. (B)
- Legislation to reduce pollution from tires;ZOAB and infiltration in road verges (Nl)
- Euro standards (for vehicles);Reduction of toxic metals (e.g. zinc) in road infrastructure (guardrail, asphalt, signs);(F)
- https://www.vlaanderen.be/basisbereikbaarheid/hoppin --> improve basic accessibility public

- The DMR (MTE) commissioned CEREMA to update the road pollutants, in order to better target the pollution abatement works to be prioritised. (F) *treatment*

4.2.2 Collection

Quantitative analysis

The answers on the closed question "what are the strategies to collect runoff water from the roads in your country?" were as follows:



This indicates that ditches and gullies are the most frequently used strategies for road runoff collection.

Qualitative analysis

The open responses provide additional insights into innovative approaches and national guidelines for the collection and infiltration of road runoff. For the purpose of this analysis, it is considered 'collection' if infiltration happens very close to the source. A few notable trends and highlights include:

- Local Infiltration and Sewer Relief: Both the VSA guideline in Switzerland and the R0 North project in Belgium emphasize infiltrating rainwater as close to the source as possible. This helps to relieve pressure on sewer systems and strengthen the local water balance. This is achieved by using infiltration berms, green zones, and infiltration ditches. More information
- Innovative Water Treatment Systems: The Swiss responses mention the use of adsorber systems and the potential for pre-treatment of road runoff before it is discharged into surface waters or infiltrated. Examples also include road wastewater treatment plants (SABA), which use filter layers, reed beds, and settling basins to purify water. Collection is the first part of these pre-treatment systems. More information
- Use of Permeable Surfaces: The carpool parking project in Landen, Belgium, provides an example of using permeable pavement and grass concrete tiles for local infiltration. This design helps manage runoff by gradually releasing it into the ground. This means that the collection here happens directly trough the permeable pavement. More information
- Storage and Buffering: The examples also mention the use of buffer basins and technical systems such as the French guidelines for stormwater storage with plastic crates, which points to an active approach to buffering large amounts of rainwater and gradually discharging it. More information

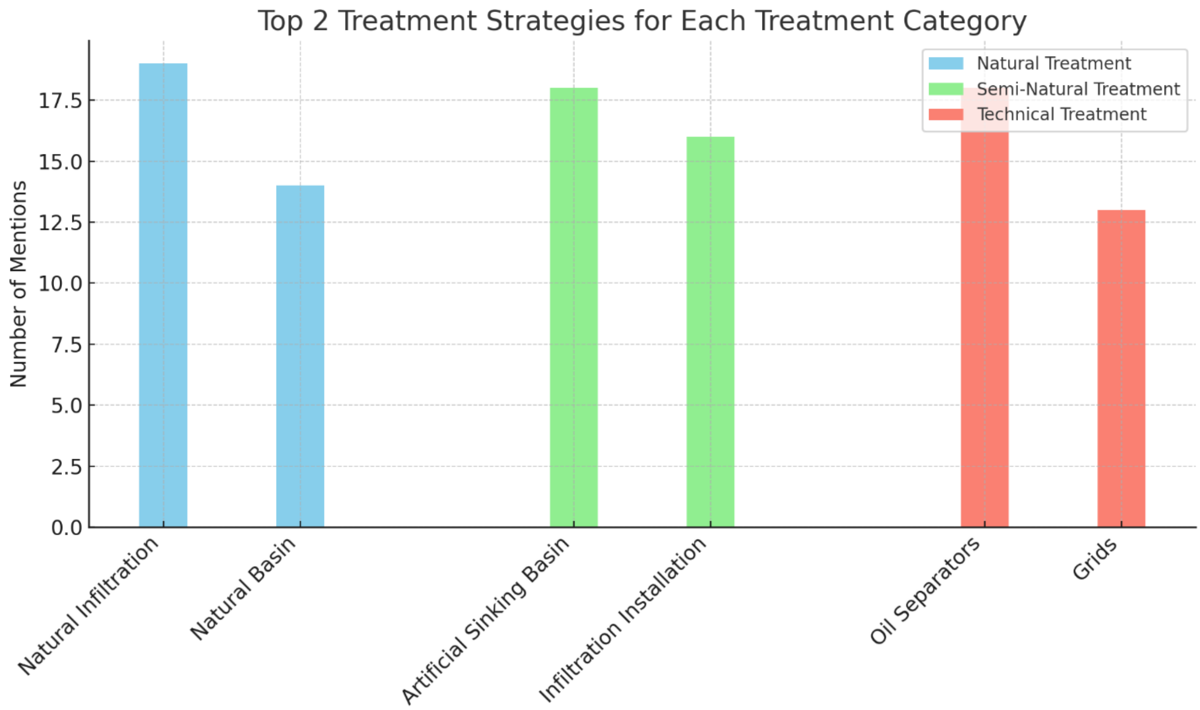
The open responses provide valuable examples of innovative strategies and national guidelines focusing on local infiltration, pre-treatment of polluted water, and permeable surfaces to manage both the volume and quality of runoff water in the collection phase. These approaches contribute to a more robust and sustainable water management system that protects infrastructure while supporting ecological balance.

4.2.3 Treatment

For the purpose of this analysis, treatment includes cleaning, treating, and filtering road runoff water to ensure it meets environmental standards before reuse or discharge.

Quantitative Analysis

The responses to the multiple-choice questions on different treatment strategies were as follows:



The quantitative analysis of the graph comparing the top two treatment strategies for each category reveals a clear preference for certain methods, while also showing that all three treatment categories are comparably represented:

Natural Treatment: The most mentioned strategies were Natural Infiltration with 19 mentions, followed by Natural Basin with 14 mentions.

Semi-Natural Treatment: The two most cited semi-natural strategies were Artificial Sinking Basin (18 mentions) and Infiltration Installation (16 mentions). Both approaches are widely applied, reflecting the importance of combining natural processes with engineered structures to manage water treatment.

Technical Treatment: The most frequently applied technical treatment methods were Oil Separators (18 mentions) and Grids (13 mentions). These methods are popular for their efficiency in removing pollutants such as hydrocarbons from runoff water before it is released into the environment.

Qualitative Analysis

The open responses provide further insight into various innovative and traditional treatment approaches for road runoff:

Local Infiltration and Pre-Treatment in Switzerland: The VSA guideline in Switzerland promotes infiltrating water locally where possible and defines specific conditions for direct discharge or pre-treatment of road runoff. The adsorber systems are one of the options used for pre-treatment. More information.

Road Wastewater Treatment Plants (SABA): The SABA system represents an example of comprehensive treatment of road runoff before discharge. This system combines different methods, such as filter layers, reed beds, and settling basins. More information.

Helophyte Filters in Ketheltunnel: Helophyte filters have been used for natural treatment in various locations, such as the Ketheltunnel in the Netherlands, where a very long helophyte filter ensures purification.

Reed Systems - ADEPTE Project: The ADEPTE project used reed systems for treating runoff water. More information.

Lime Treatment in Denmark: In Copenhagen, lime treatment is used for road runoff. This patented technology uses lime to treat and neutralize pollutants in runoff water.

Hydrodynamic Pollutant Capture: A compact technology for capturing pollutants, including microplastics, TSS, heavy metals, and hydrocarbons, has been mentioned for road runoff treatment before discharging into water bodies.

Lava Stone Autoepuration: In some regions, lava stones are used to enhance the autoepuration process of road runoff. More information.

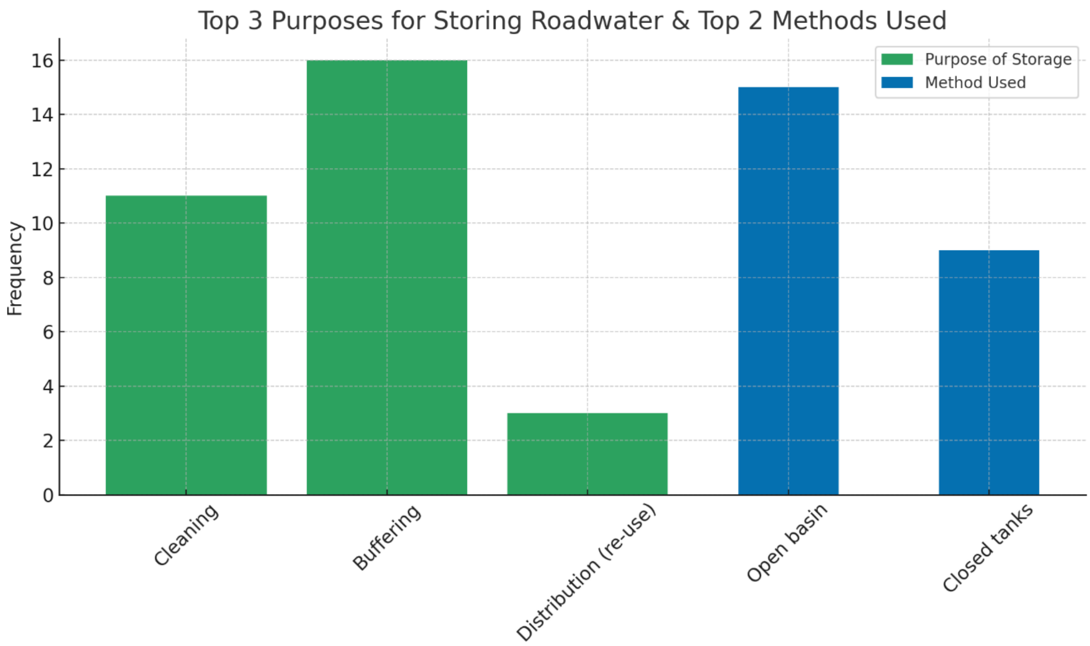
The open responses showcase a variety of strategies, from natural and semi-natural infiltration systems to advanced technologies, all contributing to the effective treatment and purification of road runoff. The emphasis is on combining traditional techniques with new innovations to ensure that runoff meets environmental standards, supports local water balance, and minimizes ecological impact.

4.2.4 Storage

For the purpose of this analysis, storage entails a place where water is stored for a period, either before or after treatment, and later to be discharged, distributed, or used.

Quantitative Analysis

The responses to the multiple-choice questions regarding the purpose of storage and the methods used were as follows:



This graph combines the primary purposes of storage, followed by the most used methods of storage.

Purpose of Storage: The top three purposes for storing road runoff water are Buffering (16 mentions), Cleaning (11 mentions), and Distribution (reuse) (3 mentions). Buffering is the most common purpose, followed by cleaning.

Methods of Storage: The two most frequently mentioned methods for storing road runoff are Open Basins (15 mentions) and Closed Tanks (9 mentions). Both methods are widely applied, with open basins slightly more common.

Qualitative Analysis

The open responses provide further insight into various approaches for storing road runoff water:

R0 North Renewal Project: In the renewal of the R0 North (Ring around Brussels in Belgium), a strong focus is placed on infiltrating rainwater as close to the source as possible. Overflow from larger rainfall events is stored in buffer and infiltration ditches or directed to sewers (e.g., near bridges or tunnels). This approach helps manage excess water effectively and supports water storage in suitable areas.

French Technical Guidelines for Plastic Crate Stormwater Storage: The French guidelines discuss using plastic crates for stormwater storage, which helps in buffering large amounts of rainwater and gradually releasing it. More information.

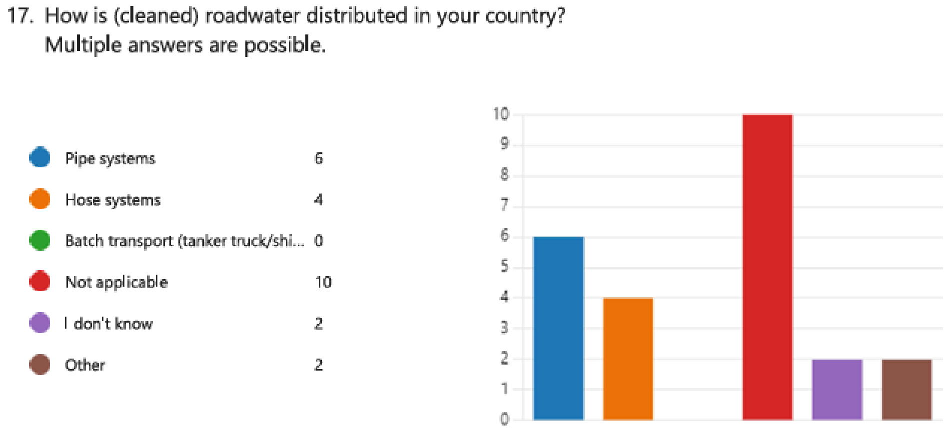
The open responses highlight a range of approaches to storing runoff water, with a focus on managing excess water through buffering and gradual release, both before and after treatment. These methods contribute to a more controlled and sustainable water management system that ensures runoff is stored and released safely.

4.2.5 Distribution

For the purpose of this analysis, distribution implies means to deliver (clean) water to possible uses or users with the purpose of re-using it. The focus is on understanding the various methods applied for transporting water from storage to its next point of use, such as irrigation or industrial applications.

Quantitative Analysis

The responses to the multiple-choice question on the distribution of treated road runoff were as follows:



Pipe systems were mentioned 6 times and hose systems 4 times, indicating that both methods are used but not extensively (out of 21 total responses). Notably, Batch Transport was not mentioned at all, suggesting it is not used among the respondents. Overall, distribution is mentioned less frequently compared to elements 2, 3, and 4, indicating it may be a less common focus or priority in the context of road runoff management.

Qualitative Analysis

The open responses provide further insights into the various distribution methods for road runoff:

Swales (Belgium): Swales are used for managing stormwater by facilitating infiltration and conveyance. This approach supports both collection and distribution of runoff water. More information.

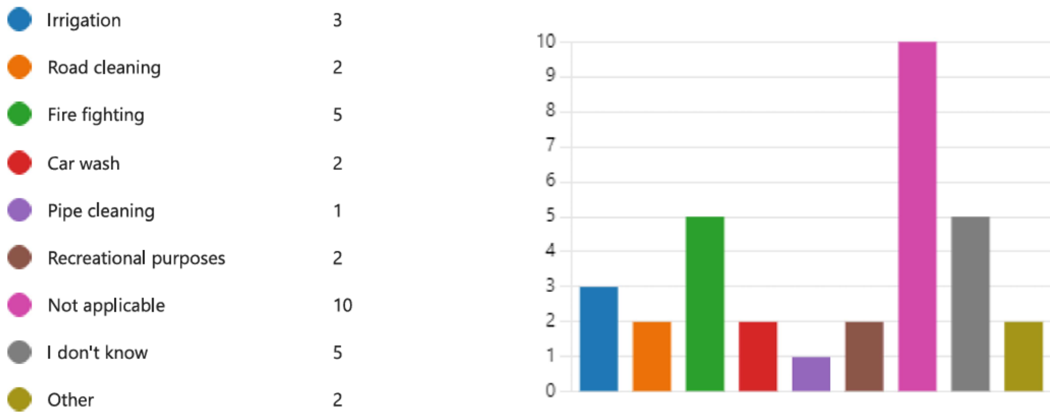
Hypotheses for Water Transport (France): In France, various hypotheses were proposed for transporting water from storage basins, including pumping after filtration, using pipelines, tanker truck transport, or even helicopter suction. However, helicopter transport is considered impractical near busy roads, but could be viable in remote areas.

F2AGRI Project (Belgium): Piping networks have been installed to distribute treated wastewater under pressure, emphasizing an infrastructure-based approach to transporting treated water to points of reuse.

These methods show a few examples of how treated water can be distributed for beneficial reuse, but the main conclusion is that it is not done a lot yet. This highlights the need for more widespread implementation to contribute to sustainable water resource management.

4.2.6 Use/reuse

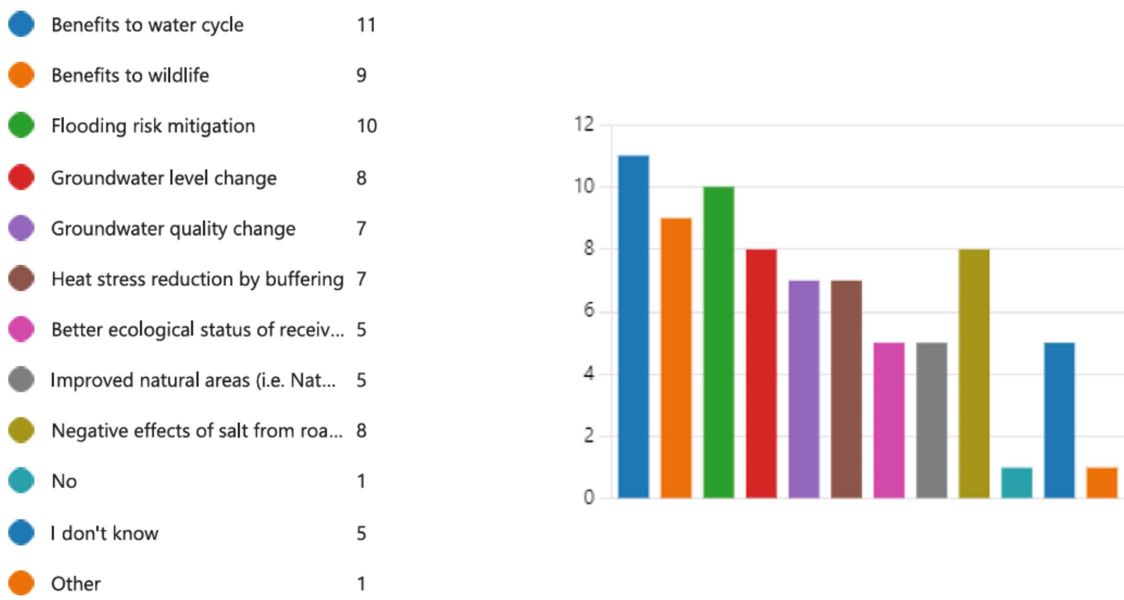
19. What use is currently applied in your country?
Multiple answers are possible.



- Sometimes used for agriculture or greywater use (e.g. irrigation of trees in parks). Large cities like Antwerp are investing heavily in circular water use.
- September/October 2024, we should be able to know whether the water in our ponds will be compatible for reuse for fire protection. The only obstacle that could exist would be if the thresholds on the parameters sought exceed the regulatory standards. (F)

4.2.7 Ecosystem balance

23. Do you already see positive/ negative effects on the ecosystem from roadwater re-use?
Multiple answers are possible.

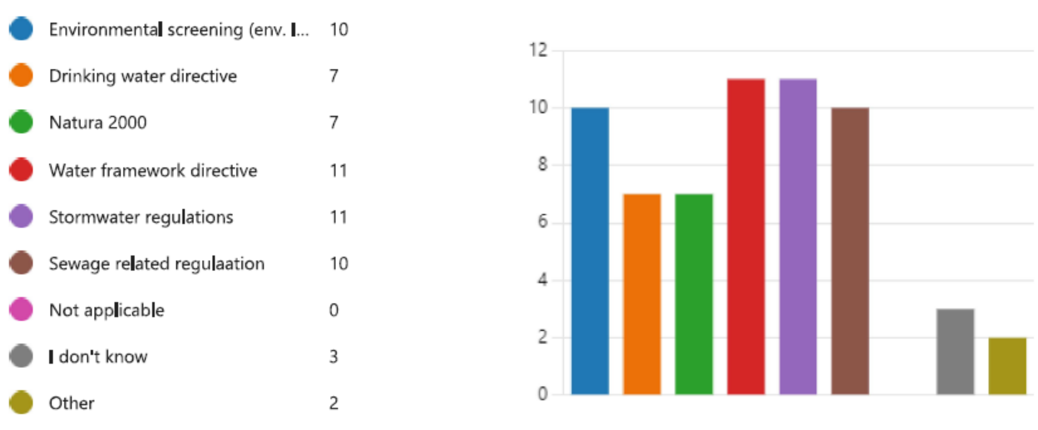


- the negative effects of salt were studied in a former project at RWTH Aachen University where I was involved. (CH) *treatment*
- https://mow-vlaanderen.foleon.com/activiteitenverslag/activiteiten-verslag2023uitgave2024/stakeholderscampagnes (B)
- Currently, during the works of the Scheldt-tunnel, a project is developed to bring water from the Oosterweel connection to the Blokkersdijk nature reserve to increase the groundwater level in that area. Drainage of the construction pit is being purified through carbon filters followed by a helophyte filter field (cleans the waste water with helophytes (marsh plants) ; the roots of these plants are responsible for a large part of the purification. Helophytes is the collective name for plants that grow above water, but with their roots in wet soil. They can even take root in the water bottom where there is no oxygen. Helophytes can transport oxygen to their roots themselves. This oxygen transport is the characteristic of helophytes). (B) *treatment*
- The primary objective of our project is to allow the filling of tanks that are distributed in the forest massifs by the SDIS and municipalities. The reuse of basin water in this sense would save groundwater resources and not use drinking water to extinguish a fire. In recent years, with climate change, we have noticed that some municipalities in the south of France (departments 66, 34, 30) have shortages of drinking water and must be supplied by tanker trucks. We find it harmful to use drinking water to extinguish a fire. (F) *re-use*
- https://document.environnement.brussels/opac_css/elecfile/BRO_Gestion_des_eaux_pluviales_23_FR_WEB.pdf (B)

4.2.8 Legal frameworks & boundaries

Legal frameworks vary from EU via national to local directives. Road Authorities have water frameworks related to the EU Water framework directive. Interesting is that roadwater is not having an own legal status like for 'drinking water' or 'waste water'. This gives legal space but also complications, as in from which juridical directive to analyse future pilot site experiments. For example, In Flandres Water Reuse for irrigation requires a 'watertoelating', but Roadwater is not considered (yet) in this legislation. Switzerland issued an environmental law to clean roadwater before discharging it into the groundwater. This resulted in many SABA's (Strassenabwasser-Behandlungsanlagen / Street wastewater treatment plants) along Swiss highways.

29. What are the juridical instruments on environment or (re-)use you have used, needed to apply, take into account or have met related to the water management for a road project to your knowledge?



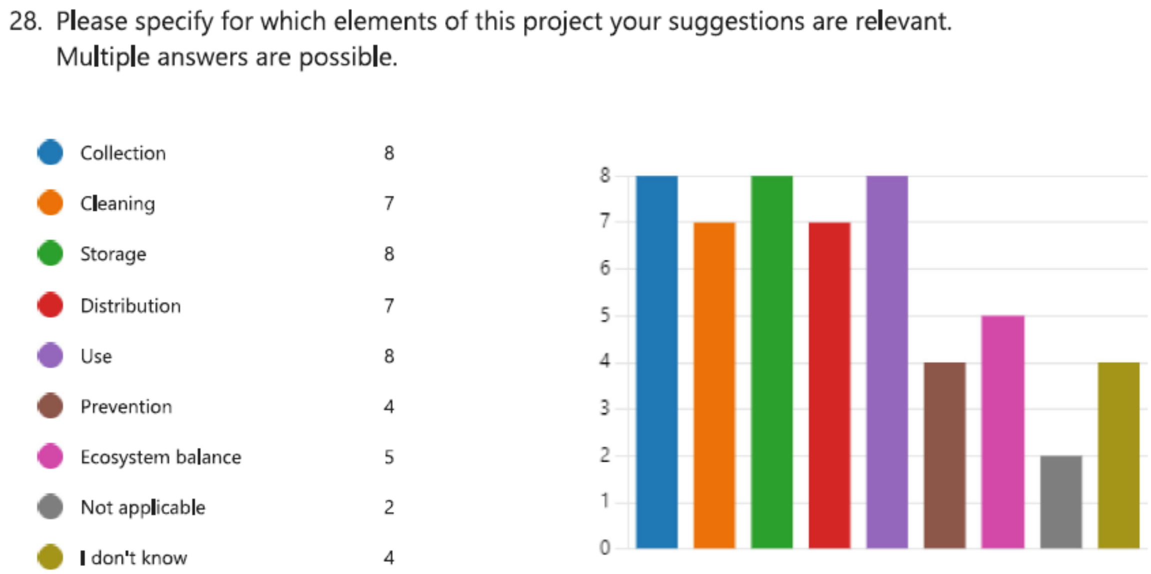
List of mentioned websites:

- T: rainwater regulation (provincial/regional): https://Omgeving.vlaanderen.be/nl/verordeningen/de-gewestelijke-hemelwaterverordening-2023
- code of good practice sewerage systems: https://www.integraalwaterbeleid.be/nl/publicaties/code-goede-praktijk-rioleringssystemen
- Vlarem II and appendices: https://navigator.emis.vito.be/detail?woId=263&woLang=nl
- environmental permit decree: https://navigator.emis.vito.be/detail?woId=63105&woLang=nl
- BBT studies: https://emis.vito.be/nl/bbt"
- https://document.environnement.brussels/opac_css/elecfile/BRO_Gestion_des_eaux_pluviales_23_FR_WEB.pdf

4.2.9 Potential IT solutions

Most used IT solution is GIS-analysis. Quite some respondees monitor for example water quality of road basins, average daily traffic, pipe systems, hydraulic capacity, groundwater protection zones, even road run-off quantitiy, not quality. An example is the Flandres Water Toets.

IT-suggestions elaborate on GIS-analysis mostly towards real-time monitoring of water supply and demand. Most existing IT-solutions (see figure below) are to be expected in the elements collection, cleaning, storage, distribution and use. There seems to be less experience with IT using in the elements of prevention and ecosystem balance. The lack of experience in prevention seems promising because some project partners [eg Gerophyt] have clear ideas on how to elaborate on this. In the Swiss pilot site of Winterthur this element will be taken up and possible solutions investigated.



4.3 Discussion on survey results

Distribution and response

The questionnaire has been distributed in Belgium, France, Germany and The Netherlands by direct e-mail from the partner organizations to their professional network, from ruralroadwaterrescue@rws.nl and published on the website https://rural-roadwater-rescue.nweurope.eu. Approximately 150 professionals where reached, of which about half in Belgium. The response has been 21, of which most from Belgium and France. That means that the approached number of people in the different countries were not balanced as well as the response. The outcome is therefore indicatory.

Focus per country

Nevertheless some differences in experiences and approach of road water runoff in different cooperating countries seems to emerge. Water basins to collect road water runoff near highways seems to be most widespread in France, which can explain the focus on firefighting as way of re-use, which was mentioned by several respondents. In Belgium focus seems to be on prevention, predominantly by stimulating modal shift (for instance cycling as alternative to driving).

A clear focus does not emerge for Germany and the Netherlands, due to limited response to the questionnaire and/or less attention to the topic compared to France and Belgium.

Results per element

In Rural Roadwater Rescue seven elements are recognized which are assumed to be indispensable in developing Climate Adaptive Waterhubs. The Partner Data Collection preceding the questionnaire gave a first impression of the knowledge and experience per country per element. This impression is showed in Figure 17.

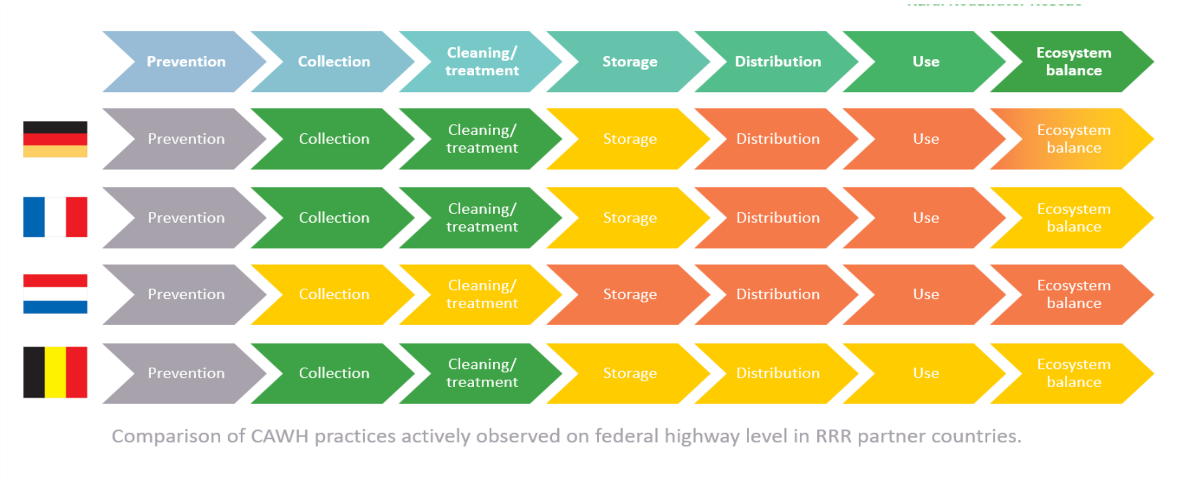


Figure 17 : Comparison of CAWH practices actively observed on federal highway level in RRR countries. Legend: red: not implemented, yellow: partially implemented, green: implemented.

The results of the questionnaire seem to confirm above figure. A more thorough analysis of the partner data collection and the response to the questionnaire shows no existing example of a Climate Adaptive Waterhub. No location has been found where all seven elements to form a Climate Adaptive Waterhub have been addressed.

Most information has been delivered on two out of seven elements, namely ‘collection’ and ‘treatment’. It seems that these two elements are most developed in the partner countries and knowledge and experience are possibly sufficient as input for designing Climate Adaptive Waterhubs. The knowledge and experience on the other five elements are limited and therefore insufficient. Future studies and experiments should predominantly be directed to gaining more knowledge and experience on these five elements.

The less information has been given on the element ‘ecosystem balance’, whereas it is a key element in Climate Adaptive Waterhubs. The whole purpose of Climate Adaptive Waterhubs is to have roads contribute to social and ecological restoration/development. But ‘ecosystem balance’ seems up to now not to be very much in focus of the network addressed with the questionnaire. It can be considered to broaden the network with stakeholders who can deliver more ideas, knowledge and expertise to this element. In that respect there are early ideas to give water a voice as stakeholder in spatial development projects. To develop ‘the voice of water’ as equivalent to other societal voices can be a challenge for the follow-up.

Conclusions and Recommendations

- Partner data collection and questionnaire should be considered as first step in developing Climate Adaptive Waterhubs. Additional information can be found by broadening the network[4]. Out of the box can also be learned from other initiatives such as flood protection.
- However no location has been identified where all elements are developed to form a Climate Adaptive Waterhub still the idea of the seven elements stands.
- In a follow up attention should be paid to balancing the seven elements by collecting more information and experiments.
- In balancing the seven elements it is important to develop ‘the voice of water’ to equal the element ‘ecosystem balance’ to the other six elements.

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[4] For instance the French Direction Interdepartementale des Routes executed a study on reuse of road basin water and CEDR conducted a to RRR related research project CEDR-Call-2015_Summaries-WATCH.pdf

5 Summary on Road Water Practices in the Partner Countries

According to the seven elements that have been categorized as relevant for the road water management strategies in North-West-European countries, Table 4 summarizes the key elements already implemented as described in detail in Chapter 2 for the four RRR-partner countries. For better overview, the progress of implementation of actions within these 7 steps is strikingly demonstrated through colours in Figure 17.

Table 4: Summary of roadwater practices in partner countries

	Germany	**France**	**Netherlands**	**Flanders**
Prevention	Mobile shift	Waterproofing ditches or basins in high vulnerability zones	Updating/maintaining roadside furniture, non-tar-containing asphalt	Mobile shift towards bikes
Collection	Gullies	Ditches, pits and gutters, pipes	Shoulders, Manhole into collection sewer, ditches	Open (concrete) ditches, piping, gutters
Cleaning/ Treatment	Sieve/ grid, particle separator, oil separators, reed system, sedimentation basin, infiltration	Decantation with retention basin with dead volume. Infiltration after treatment	Infiltration into shoulders or ditches, oil separator, retention facility, sewer	Infiltration, pilot treatment systems for collected water
Storage	tanks to collect a certain amount of water for pre-cleaning, open semi-natural basins to store and clean water before infiltration to environment or release to river, buffer tanks for extreme water volumes	Temporary to avoid flooding	None	Basins (buffering), different types exist: evaporation, infiltration, concrete bottom
Distributio n	None, only release to natural water cycle (infiltration or release to rivers)	None.	None, only infiltration to natural water cycle	Pilots – experimenting
Use	None	None	None	Pilots – experimenting
Ecosystem balance	Benefits to water cycle to recycle water unable to seep on sealed road areas	Basins with water all year tend to provide refuges for the fauna. Protected species of plants are also found on some basins.		Positive from a quantitative (ground & surface) water and qualitative surface water point of view, uncertainties on ground (& drinking) water quality aspects

6 Promising Sites for Future Implementation

Introduction

The communities we want to involve in water management are typically location-based. This raises the question of what comes first: selecting the community or determining the location. And, regarding community and location, what size or area do we have in mind or seems logical? Within this community, who should be involved and how do we get to know them? We actually don't know what we are unaware of. There is no logical order in progressing and the only way to find out, is to look at promising locations and communities and go talk to them.

Next, we will look at an approach in determining what could be promising in terms of location, allowing to determine an initial scope for further examining of the local context. We draw from examples of how the process of identification actually went in different locations, showing that many triggers and routes are possible and there is no such thing as a one-size-fits-all solution.

Locations

When identifying locations, we look for places with chances or problems. Chances may also rise as a spillover from solving problems. One might do better than just solve the problem. Chances can be discovered by taking different perspectives on places: geological, hydrological, landscape layout, assets and infrastructure, motivation and (land)ownership, institutional/governmental jurisdiction and scale. We will now further explain these.

When reviewing the **geological, hydrological and landscape layout** situation of a location, one could assess the quantity and quality of water bodies (lakes, rivers, streams and canals), types of soil (more or less water-absorbing, prone to erosion or landslides), groundwater levels (increasing/decreasing), differences in landscape (flat/hills, urban/rural, vegetation, nature, agriculture), weather and climate conditions causing heavy rains, mudslides and flooding, problems of drought and salination (at the seaside).

We've seen flooding of highways in Germany, diverse urban areas with (canalised) rivers overflowing their banks (throughout Europe), man-made canals blocking the natural groundwater flow and tunnels leaking and draining groundwater (NL), and problems arriving with the rising of groundwater levels around a former coal mine (Bergheim, DE).

Periods of drought have resulted in water restrictions and mandatory reporting of smaller, shallower groundwater wells to local water authorities (NL, no new ones allowed) impacting agriculture and forcing changes in farming practices. We see adaptations to existing homes and buildings, such as removing pavement (increase infiltration), installing rainwater collection systems (conserve water) and redirecting stormwater away from sewage systems (preventing overflow).

The discharge of pollution to rivers and streams has a huge impact on the water quality. This may, for example, come from the process industry (chemicals, PFAS), agriculture (pesticides and fertilizers) and road run-off (e.g. microplastics, salt and oil). Where possible, pollution should be prevented at the source. We've also seen situations, especially in dry periods, where rivers carry less water and the concentrations of pollution become so high that they lead to massive dying of fish. Or drinking water companies, that take water in from the river and more often need to temporarily stop the intake of water due to high concentrations of pollution.

Existing and planned **assets and infrastructures** in an area also provide chances for water hubs. These assets might be leveraged and used to contribute to better water management. For example, roads can be leveraged to not only provide mobility, but also act as large collectors of water. Roadwater can provide a valuable contribution to the water supply at moments of water scarcity, when collected, buffered and cleaned, and at the same time this prevents polluting the environment and surface water. In times of heavy rainfall and flooding, buffering roadwater can help to prevent it from causing problems in other locations, such as agricultural land, built environment/sewers and in drainage canals, streams and rivers.

Another way of thinking is that assets can be combined or extended to serve similar purposes. An example of this is a waste water treatment facility near the highway (Aachen, Germany), that might also be used to clean roadwater that is currently discharged into a stream untreated.

Assets may be relieved, such as the drinking water production facilities or pumping installations. Some drinking water companies in The Netherlands do not have enough (capacity) sources to provide water during dry periods or to extend to new neighbourhoods. Offloading the tap water and ground water use, by providing alternatives for households (to water the garden) and for farmers (to water the fields) will relieve the drinking water infrastructure.

Finally, a location might be very appropriate for the introduction of new (water hub) assets that help balancing the water system, such as providing a large area for buffering water.

Motivation, sense of urgency and (land)ownership are other factors that increase the chances of successfully introducing water hubs, where ownership can be both understood as problem ownership and land ownership (we will come back to that).

Typical questions to be asked are:

1. What are locations that have experienced problems, where people and governments are aware of water issues and are willing to take preventive measures?
2. In which places is community involvement required because the government is no longer able to solve the issues alone?
3. In which areas do individuals need each other's help because they cannot (efficiently) solve the problems by themselves anymore?

Important is the need for collective action. If an individual is able to solve a problem singlehandedly, then there is no incentive to work together. However, this collective-problemownership is required but not enough. The local community must also be able to influence possible solutions, raising questions such as “Who owns the land?” and “Who owns important assets?” In other words: Is the local situation community-ownership-aligned?

It is important to find out **what organisations or governments have jurisdiction** in a certain area and at what level they operate (local, regional, national, EU). The “further away” these organisations stand from the specifics of the local situation, the more difficult it will be to involve them in customized local solutions. Typically, higher governments also work on different (larger) time scales with respect to developing and realising. However, if you happen to succeed in involving a higher government, this may very well provide leverage to your project and to other organisations required to participate. In short, organisations and governments with jurisdiction in the area can both increase or decrease chances of success.

The appropriate **size or scale** of an area is much debated. We suggest finding a balance between keeping it “small, simple and easy for decision making” and “large enough to allow cost-effective implementations”. Too small and you will lose the aspect of collective problem-ownership as discussed, too large and the decision making, the number of parties and the complexity will take away any chance of success within a reasonable time frame. We found that keeping the scale limited leads to a closer involvement of the local community and to easier decision making, while it still allows to work together with other initiatives on joint topics. However, it doesn’t come with the difficulties of a large organisation and it accommodates different speeds and timelines for initiatives, not holding each other back, but inspiring each other.

To conclude: Promising locations for climate adaptive water hubs can be found by taking different perspectives on chances and problems, such as the ones described above, and see if they strengthen each other. It will be a creative process of connecting the dots, weighing the pros and cons and making educated guesses.

7 Relevant Links

7.1 Germany

Richtlinie für die Entwässerung von Straßen", 2021: ARS 6/22 (fgsv-verlag.de) ; REwS (fgsv-verlag.de)

Abwasser-Verordnung (AbwV): https://www.gesetze-im-internet.de/abwv/

7.2 France

Technical guidelines

Assainissement routier : Guide technique - Cerema

Pollution d'origine routière : Conception des ouvrages de traitement des eaux - Guide technique - Cerema

https://www.astee.org/publications/memento-technique-2017/

GUIDE OPUR - Infiltrer les eaux pluviales | Graie

Report on road pollution measures (2021):

Qualification et caractérisation des pollutions chroniques routières - Cerema

Presence of mosquitos in basins in the north and east of France (2024):

Suivi des larves de moustiques dans les bassins d'assainissement routier : campagne Hauts-de-France 2023 - Cerema

Les communautés de moustiques dans 6 bassins routiers de Lorraine - suivi 2023 - Cerema

7.3 Netherlands

Kader Afstromend Wegwater:

https://open.rijkswaterstaat.nl/zoeken/%4041070/kader-afstromend-wegwater-kaww/

Water management for road authorities in the face of Climate Change (WATCH)

PEB: Research Call 2015 - Climate Change: From Desk to Road (cedr.eu)

7.4 Flanders

Relevant legislation in Flanders of how to deal with runoff water from roads

https://www.integraalwaterbeleid.be/nl/publicaties/code-goede-praktijk-rioleringssystemen

https://www.integraalwaterbeleid.be/nl/beleidsinstrumenten/watertoets

https://www.integraalwaterbeleid.be/nl/beleidsinstrumenten/signaalgebieden

https://www.vmm.be/wetgeving/hemelwaterverordening

Relevant guidance documents for designing new highway road infrastructure in Flanders

https://wegenenverkeer.be/zakelijk/documenten/ontwerprichtlijnen/weginfrastructuur#:~:text=Het%20Vademecum%20weginfrastructuur%20is%20standaard,het%20ontwerp%20binnen%20verschillende%20contractvormen.

Studies

Sanitation techniques and composition runoff water in Flanders: https://www.vmm.be/publicaties/sanering-wegwater-verkenning-technologische-mogelijkheden-case-studies

Microplastic study in Flanders:

https://www.vmm.be/nieuws/archief/microplastics-in-oppervlaktewater-laag-tot-verwaarloosbaar-risico

Article on groundwater discharge by renewed stormwater decree quantitatively that uplift the strict rules for infiltration in protected zone 3 of drinking water abstraction sites https://www.sciencedirect.com/science/article/pii/S2214581824000958?via%3Dihub

8 Synthesis of research projects on roadwater in France

8.1 Introduction

The objective of this review, according to the RRR project definition, is to share French experiences and expertise on the characterisation of road runoff from two previous projects in which Cerema participated, named “Roulepur” (2014-2020) [1] and “chronic pollution characterisation of road runoff water” (2017-2021) (hereinafter referred as “Micropolluants routiers”) [2]. Nevertheless, reader should be aware that this review is a non-exhaustive synthesis and for more information it should refer to main documents of each project.

See separate PDF or https://rural-roadwater-rescue.nweurope.eu/

8.1.1 Legal regulations in France

Since 2000, the Water Framework Directive - 2000/60/EC (WFD) [1] requires all European countries to ensure good environmental status of water bodies. The WFD has been transposed into French law, first in 2004 - Loi 2004-338 du 21 avril 2004 [2], and then in 2006 with the LEMA – Loi sur l’eau et les milieu aquatiques [3].
Road runoffs are a source of pollution to water bodies. Pollutants in road runoffs need to be identified and monitored in order to allow the WFD objectives to be reached. Road runoff pollutants are numerous and of diverse origins (see 8.2.3). 45 of those pollutants, among which some trace metals and organic micropollutants, are listed by the WFD as priority substances (WFD - Annex X) [1], as they were considered as the greatest concern to the aquatic environment when the WFD was formulated.
In France, from 2016 to 2021, the French Ministry of Environment in collaboration with both Health and Agriculture Ministries established a national micropollutants plan to protect biodiversity and ensure water quality according to the WFD.
The French Ministry of Environment defines a micropollutant as « an undesirable substance detectable in the environment at very low concentrations (µg/l or even ng/l). Its presence is due, at least in part, to human activity (industrial processes, agricultural practices or everyday activities) and at these very low concentrations can have negative effects on living organisms due to its toxicity, persistence and/or bioaccumulation » [4].

More specifically on road water management, two documents were written by the SETRA (Service d’Etudes Techniques des Routes et Autoroutes) – became Cerema since 2014 - and give guidelines for good road runoff management: the technical guide to road drainage (GTAR) [5] and the road pollution technical guide (GTPOR) [6] to design water treatment facilities dedicated to road infrastructures.

8.1.2 Objectives of the review

The objective of this review, according to the RRR project definition, is to share French experiences and expertise on the characterisation of road runoff from two previous projects in which Cerema participated, named “Roulepur” (2014-2020) [7] and “chronic pollution characterisation of road runoff water” (2017-2021) (hereinafter referred as “Micropolluants routiers”) [9]. Nevertheless, reader should be aware that this review is a non-exhaustive synthesis and for more information it should refer to main documents of each project.

8.2 Bibliographic review

8.2.1 Research projects consulted

8.2.1.1 *The Roulepur project:* “Innovative solutions for controlling micropollutant contamination at source in runoff water from urban roads and car parks

The Roulepur project aims to evaluate the treatment performances of innovative solutions for a better management of the micropollutants contamination at its origin inside road and urban parking lots run-offs. It took place from 2014 to 2020.
The project has several objectives [7]:

- improve knowledge on the chemical composition and toxicity of road and parking lot runoff, to then prioritize issues related to their management;
- identify the primary sources of contamination, to guide emission reduction strategies;
- evaluate in situ the effectiveness (both from hydrological point of view and water quality point of view) of four innovative source control solutions of different types; assess the sustainability of these solutions (maintenance, aging) and analyse their overall envi-ronmental performance over the whole life cycle;
- assess the social, technical and economic acceptability of these solutions and evaluate their diffusion potential based on the technical and institutional local context.

This review relies on the PhD thesis of Kelsey Flanagan [8] which focuses on the analysis of the treatment of road runoffs pollutants in two biofilters, a vegetative filter strip and a biofiltration swale, as part of the Roulepur project.

8.2.1.2 “Micropolluants routiers”: Qualification and characterisation of chronic pollution of runoff water from urban roads

The « Micropolluants routiers » project is a study led by Cerema from 2017 to 2020 for the Transport Infrastructure Department of the French Ministry of Environment. Prior to that, in 2014, Cerema es-tablished a measurement protocol to qualify pollution in road runoffs. The « Micropolluants routiers » project applied this protocol on three French road catchments in order to monitor and identify pre-cisely the pollutants present in road runoffs.

This review relies on the study report of the project [9].

8.2.2 Study sites reviewed

In “Micropolluants routiers”, the road runoff is managed with facilities (often basins) where the pollutants settle down before the reject to the environment (see Fig 1).

The runoff analysed here is measured and sampled in the inlet pipe transferring the runoff from the colleting pipe to the basin. The collecting of the road runoff can be of various types. For

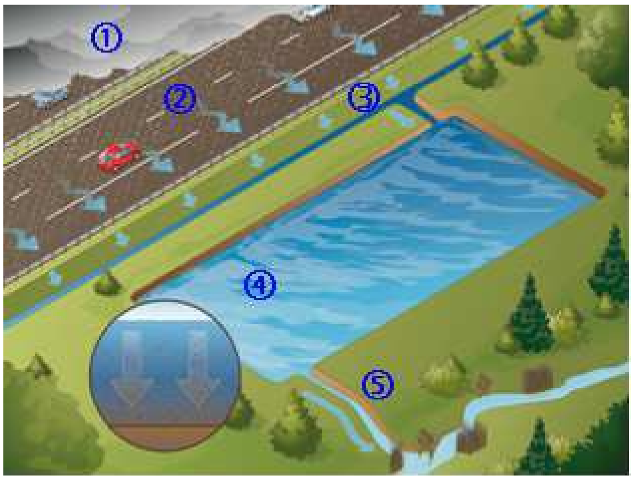

Fig 1. Principle of the road runoff treatment in Micropolluants routiers
1 : rain, 2 : runoff, 3 : runoff collecting, 4 : treatment by settling, 5 : reject to the environment

site 1, it was a slot channel (see Fig 2) and for sites 2 and 3, it was a U-shaped channel (see Fig 3).

Fig 2. Collecting of road runoff by a slot channel

Fig 3. Collecting of road runoff by a U-shaped channel

In Roulepur, the runoff is measured and sampled in a sewage manhole, see Fig 4.

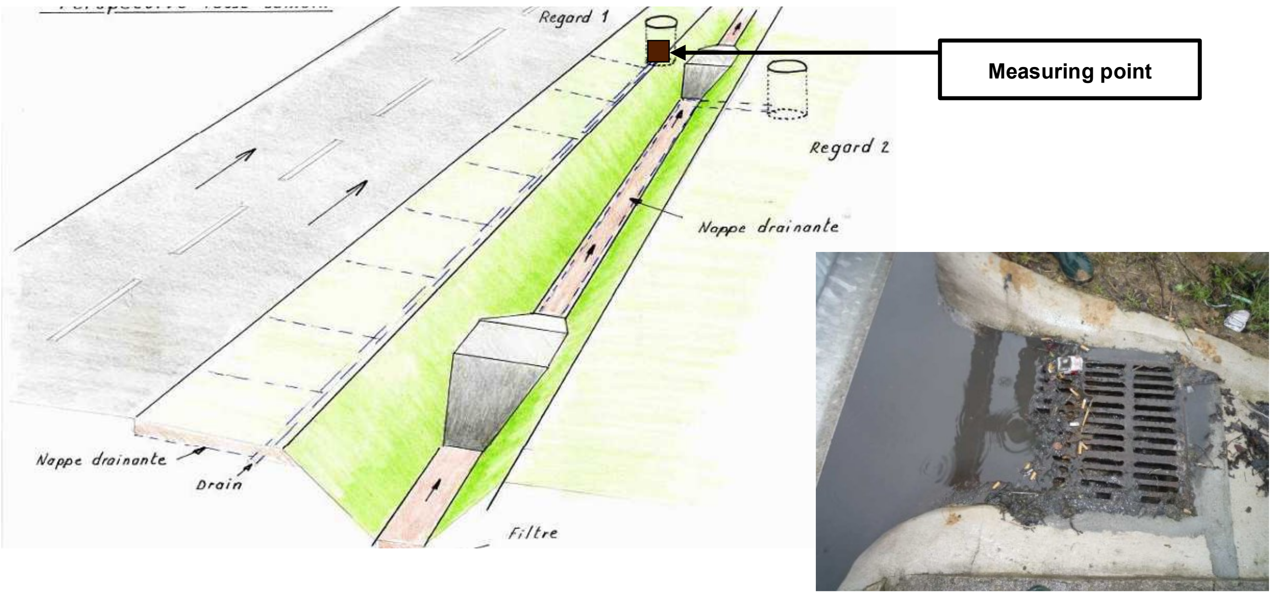

Fig 4. Schematic diagram of the Roulepur measuring point, Thomas 2012; Flanagan, 2018

The following tab shows the location, traffic volume and total surface of the catchment for the study sites reviewed for each research project. The four studied locations belong to the highest category of traffic volume.

Tab 1. Main characteristics of the study sites

Research project	Location	Traffic volume (vehicles/day)	Percentage of HGVs[5] (%)	Total surface of the catchment (m^2)
Roulepur	Compans, Seine-et-Marne (77), Ile-de-France	22 000		945
Micropolluants Routiers Site 1	Ile-de-France	127 700	8.1	83 000
Micropolluants Routiers Site 2	Grand Est	45 332	12	11 300
Micropolluants routiers Site 3	Auvergne-Rhône-Alpes	6 557	35	29 300

8.2.3 Pollutants in road runoff

8.2.3.1 Origin of pollutants in road runoff

The rain on impervious catchments – as roads – turns into a runoff, washing the multiple pollutants present on the surface. These pollutants can be of diverse origins: atmospheric deposit, cars and their functioning or the road itself (see Tab 2). Therefore, road runoff contains a certain amount of pollutants requiring identification and analysis in order to treat them properly and limit the pollution of the environment.

Pollutants can be classified in three major groups [9]:

- Macropollutants: global parameters as for example: TSS[6], COD[7], BOD[8], usually used to qualify water quality and design treatments
- Inorganic micropollutants: metals (trace metals and major metals) and metalloids
- Organic micropollutants, as for example: TPH[9], PAH[10], BPA[11], AP[12], PAE[13], Ethers, BETX[14].

For the two last groups, given examples are related to roadwater pollution (non-exhaustive).

---

5 Heavy Goods Vehicle

6 Total Suspended Solids

7 Chemical Oxygen Demand

8 Biochemical Oxygen Demand

9 Total Petroleum Hydrocarbons

10 Polycyclic Aromatic Hydrocarbons

11 Bisphenol A

12 Alkylphenols

13 Phtalates

14 Benzene, Toluene, Ethylbenzene, Xylene

Tab 2. Main origin(s) of some road runoff pollutants (non-exhaustive)

A grey cell means that the pollutant is produced by the element, a white one means it is not

	Metals	**TPH**	**PAH**	**BPA/AP**	**PAE**	**Ethers**	**BTEX**
Atmospheric deposit	■		■				
Exhaust gas	■		■				
Car body	■		■	■	■		
Brakes	■		■				
Tyres	■		■	■	■		
Automobile liquids *Brake fluid, cooling liquid, engine oil*		■	■	■		■	
Fuel		■	■				■
Road surface	■		■	■			
Road equipment *Signs, barriers*	■			■	■		

The detailed list of pollutants monitored in each project can be found in Appendices 1.

8.2.3.2 Pollutant phases

Pollutants can be found in particulate phase or/and dissolved phase. The repartition between these two phases depends on the nature of the pollutant, its bio-physical-chemical properties and those of the environment and so can change with time and conditions (pH, temperature…). Knowing the partitioning of the pollutants is important as it influences its behaviour and the type of treatment to use. Indeed, pollutants mostly in particulate phase will be more sensitive to retention solutions as filtration or settling (depending on the size of the particles) whereas pollutants mostly in dissolved phase will be more likely to be retained by sorption or precipitation [8].

In both projects, the dissolved phase was determined after sample filtration through a 0,45 µm filter (usual threshold between dissolved and particular). Then particular phase has been calculated has the difference between total concentration and dissolved concentration.

8.2.3.3 Comparison to threshold values

The WFD aims good quality of water bodies, including good both ecological and chemical states. The ecological state is assessed by analysing pollutants such as the global parameters and nutrients and is classified in 5 ranges from bad to high. The chemical state is assessed by comparing the concentration of the 45 priority pollutants to the EQS[15]. EQS is defined by the WFD as the "concentration of a pollutant or group of pollutants in water, sediment or biota that must not be exceeded in order to protect human health and the environment." The EQS are expressed in several ways: either as an annual average concentration (EQS-AA), or as a maximum allowable concentration (annual average) (EQS-MAC). [1], [3]

The current EQS values for some road runoff pollutants can be found in Appendices 2. In both projects, comparison could have been done between samples concentrations and EQS when existing. It gives indications, and has to be considered only like this as EQS are dedicated to water bodies quality and not to effluent quality.

8.2.4 Characterisation of pollutants in road runoff

It has to be noted that the detection of the pollutants depends on the analytic method used. The occurrence of a parameter is assessed if a pollutant is found to be in a concentration superior to its analytical Limit of Quantification (LQ). As a consequence, the non-detection of

[15] Environmental Quality Standard

a pollutant can mean either its absence in the sample or its presence in a concentration inferior to the LQ.

8.2.4.1 Rain events

The characterisation of road runoffs involves field work and especially sampling related to rain events. In “Micropolluants routiers”, the rainfall events identified are all those with a return period longer than twice monthly. The characteristics of the rain events identified are presented in the following tab (Tab 3).

Tab 3. Selected rain events characteristics - median (min; max)

Research project	Total rainfall (mm)	Mean intensity (mm/hr)	Maximum intensity (mm/hr)	Rain event duration (h)	Antecedent dry days (days)
Roulepur	7.8 (1.6; 47.2)	0.47 (0.06; 2.25)	11 (2; 43)	18.6 (2; 40)	1 (0.1; 17.7)
Micropolluants routiers **Site 1**	8.8 (2.2; 26)		4 (1.4; 9.6)		
Micropolluants routiers **Site 2**	12.6 (8.8; 30)		4.8 (2; 46)		
Micropolluants routiers **Site 3**	9.4 (4.8; 64)		4.3 (1.6; 22.5)		

Some of those rain events were then sampled and analysed. Sampling is not easy as many parameters have to be considered to obtain representative samples relevant to analyse:

- Uncertainty of the type of water to collect (reliability of weather forecast, dry time period…)
- Sufficient sample volume, to allow the different parameters to be analysed
- Compatibility between sample conservation duration and ability to be analysed by the laboratory.

The conditions of sampling differ from one project to another. In Roulepur, the sampled rain events are based on meteorological predictions of significant rainfall (>2mm). Samples were collected within 36h of the beginning of rainfall for the targeted runoff event and within 24h of the end of runoff to ensure adequate sample conservation. In Micropolluants routiers, the rainfall events identified are all those with a return period longer than twice monthly. The samples then analysed where all those that meet the conditions for a qualitative analysis (working sampling equipment, sufficient sample volume, possibility of analysis by the laboratory).

The below table indicates the number of samples that were analysed. It should be noted the difference with the number of rain events that were identified, explained above.

Tab 4. Rain events identified and samples selected

Research project	Sampling period	Number of rain events identified	Number of analysed samples
Roulepur	February 2016 – July 2017		14
Micropolluants routiers Site 1	February 2017 – June 2020	77	29
Micropolluants routiers Site 2	July 2017 – June 2020	60	8
Micropolluants routiers Site 3	March 2018- June 2020	25	10

8.2.4.2 Global parameters

The results obtained for global parameters for each project are summarized in

Tab 3.

Correlations were found between concentrations of some parameters and explanatory variables (traffic and rain events), showing that higher traffic and more intense rain events lead to higher pollutant concentrations in the runoff [8], [9].

Road runoffs are all slightly alkaline (inside the range for a “good” state) with a stable pH in both projects. Electrical conductivity (EC) is highly variable in each project, with higher values found after salt application on the road surface in winter [8].

In Roulepur and sites 1 and 3 of the “Micropolluants routiers”, median TSS concentration exceed the water quality objective, with maximum concentrations being more than 20 times higher than the objective for a good ecological state]25 – 50] mg/l. Site 2 of “Micropolluants routiers” has a median TSS concentration in the range of the objective for a good ecological state.

TOC median concentrations were found to be higher in Roulepur than in “Micropolluants routiers” (49 mg/L for Roulepur versus lower than 10 for “Micropolluants routiers”). Median DOC concentrations are inside the range for a “good” ecological state (]5-7] mg/l) except for the site 1 of “Micropolluants routiers”. Although the concentrations are of the same magnitude, the partitioning of the carbon is very different between both projects: in Roulepur, most of the carbon is particulate (88%) whereas in “Micropolluants Routiers”, organic carbon is mainly dissolved (more than 80%).

COD and BOD concentrations were only on measured in “Micropolluants routiers”. Concentrations are highly variable and largely exceed the water quality objectives, leading to a poor ecological state of the road runoffs for the two parameters.

Nutrients were only analysed in Roulepur project. Objective values for ammonium, nitrate and nitrite are respected for median concentrations. Total phosphorus median concentration exceeds the water quality objective.

Tab 3. Global parameters - median (min; max)

	pH	EC	TSS	TOC	DOC	COD-total	BOD	KN	NH_4^+	NO_2	NO_3	TP
Roulepur	8.02 (7.62; 8.41)	234 (88; 1950)	291 (70; 933)	49 (14; 111)	6.1 (1.7; 14.7)	-	-	2.92 (<1; 5.58)	0.2 (<0.04; 0.48)	<0.08 (<0.08; 0.27)	0.47 (<0.05; 1.84)	0.48 (0.13; 2.05)
Micropolluants routiers – site 1	8 (6.9; 9)	315.5 (79; 5260)	204 (30; 1110)	8.8 (5.7; 59)	7.9 (4.4; 5.9)	211.5 (49; 858)	16 (4; 79)	-	-	-	-	-
Micropolluants routiers – site 2	8 (7.5; 8.1)	249 (23; 2720)	44.5 (15; 240)	6.4 (3; 8.1)	5.1 (2.6; 7)	58.5 (34; 291)	11 (1.3; 50)	-	-	-	-	-
Micropolluants routiers – site 3	7.65 (7, 8.02)	104.5 (15, 776)	66 (7, 223)	7.7 (4.7, 27)	5.2 (3.9, 13)	76 (23, 236)	9 (2.4, 49)	-	-	-	-	-
Water quality Objective – "good" state [2]	]6.5; 8.2]	-	]25 ;50]		]5 ;7]	]20 ;30]	]3 ;6]		]0.1 ;0.5]	]0.1 ;0.3]	]10 ;50]	]0.05 ;0.2]

8.2.4.3 Metals

12 metals (Al, As, Ba, Cd, Cr, Mo, Ni, Pb, Sr, Ti, V, Zn) were analysed in both projects, whereas 3 (B, Hg, Sb) were only analysed in "Micropolluants routiers" and 7 (Ca, Cu, Fe, K, Mg, Mn, Si) in Roulepur. The detail of the analysis per project can be found in Appendices 1.

The following tab shows the order of magnitude of the measured trace metals concentrations.

Tab 4. Concentration of the trace metals
In bold, the elements found in the same concentration range in both projects

	> 1000 µg/l	100-1000 µg/l	15-100 µg/l	< 15 µg/l
Micropolluants routiers *Mean concentration*	**Al**	**Zn, Cu, Ba**	B, Ti, Sr, **Pb**, Cr, Sb	Ni, V, **As**, **Mo**, Co, **Cd**, Hg (never quantified)
Roulepur *Median concentration*	**Al**	Ti, **Zn, Cu, Ba**, Sr	**Pb**, Ca, V, Ni, Fe	**Mo**, **As**, K, Si, **Cd**, Mn

Aluminium is the most concentrated element in all samples (Roulepur median concentration of 14,4 mg/L and "Micropolluants routiers" mean concentration of 3,7 mg/L). This can be justified because of the natural high presence of aluminium in nature [10]. Mercury (Hg) was never quantified in Micropolluants routiers: its concentration was always inferior to the quantification limit of 0,5 µg/l.

Then zinc (Zn), copper (Cu) and Barium (Ba) were found in all samples in the highest concentration. Titanium (Ti) and strontium (Sr) were present in higher concentrations in Roulepur than in "Micropolluants routiers".

The partitioning of trace metals is summarized in the following tab.

Tab 5. Partitioning of the trace metals
In bold, the elements found in the same phase for both projects

	Mostly particulate (particulate fraction > 70%)	Intermediate	Mostly dissolved (dissolved fraction > 70%)
Micropolluants routiers	**Ti**, Sb, **V**, **Al**, B	Ba, Pb, Zn, Cu, Ni, Mo, Cr	Sr, As, Cd, Co
Roulepur	**Al**, As, Ba, Cu, Mo, Ni, Pb, **Ti**, **V**, Zn	Cd, Co, Sr	

Among the 12 metals studied in both projects, only 3 were determined with a similar partitioning (Al, Ti and V mostly in particulate fraction). In Roulepur project, most metals were found to be in particu-late phase and no metal were mostly dissolved. On Micropolluants routiers project, 4 metals (Sr, As, Cd, Co) were analysed as mostly dissolved. It has to be noted that arsenic (As) was, on the contrary, determined as mostly on particulate phase for Roulepur. The importance of the particulate fraction in Roulepur can be explained with the nature of the measured catchment: indeed, it was not quantified in the study. Yet, one major factor of influence could be that the road drained in the Roulepur project has a high proportion of trucks and is located in an industrial zone, near Charles de Gaulle Airport. [8] Moreover, metals are sensitive to environmental conditions (pH, salinity, oxidation- reduction conditions…) that could lead to partitioning changes. These results show how it is important runoff water to be characterized locally and over time.

The comparison of the metal concentrations with the EQS show if the runoff, before treatment, is highly polluted in comparison to the environmental limits. The following tab summarized the frequency of the EQS-AA excess for metals for both projects.

Tab 6. Frequency of EQS-AA excess for metals
Aluminium and strontium do not have an associated EQS-AA; hence they do not appear in Tab 8.

	100%	In between	0%
Micropolluants routiers		Ba, Cr, V, Ni (between 20% and 60% of samples) Sb, As, Cd, Co, Cu, Pb, Ti, Zn (> 80% of samples)	B, Mo
Roulepur	Cu, Zn	As (≈ 50% of samples)	Cd, Cr, Ni, Pb

It can be noted that frequent excess of metals EQS-AA can occur and also site variability.

8.2.4.4 Hydrocarbons: TPH[16] and PAH[17]

- TPH

TPH is a global parameter for hydrocarbon pollution. It does not have an EQS but when existing, French permitted discharge effluent concentration is commonly 2-5 mg/L. The concentrations found in both projects are inferior to this range.

The following tab shows the order of magnitude of the TPH concentrations measured and the related partitioning.

[16] Total petroleum hydrocarbon

[17] Polycyclic aromatic hydrocarbons

Tab 7. Results of the TPH analysis

	TPH (mg/L)	Partitioning
Roulepur *Median concentration*	1,12	Particulate (TPH never been quantified in the dissolved fraction)
Micropolluants routiers – site 1 *Mean concentration*	0,96	Mostly particulate (particulate fraction ≈ 80%)
Micropolluants routiers – site 2 *Mean concentration*	0,66	Intermediate (particulate/dissolved fractions ≈ 50%) *Dissolved fraction might be overestimated as analytic limit of quantification has been selected for the calculation when occurring* [9]
Micropolluants routiers – site 3 *Mean concentration*	0,34	Intermediate (particulate/dissolved fractions ≈ 50%) *Dissolved fraction might be overestimated as analytic limit of quantification has been selected for the calculation when occurring* [9]

- PAH

16 US EPA priority PAHs defined by the Clean Water Act were analysed : Naphthalene (Nap), Acenaphthylene (Acyl), Acenaphthene (Acen), Fluorene (F), Phenanthrene (Phe), Anthracene (A), Fluoranthene (Fluo), Pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene(Chry), Benzo(b)fluoranthene (BbF), Benzo(k)fluoranthene (BkF), Benzo(a)pyrene (BaP), Dibenzo(ah)anthracene (DahA), Benzo(ghi)perylene (BPer), Indeno(1,2,3-cd)pyrene (IP).

The sum of the 16 PAH values for each project is listed in the following tab.

Tab 8. Concentration of the PAHs – median concentration

	Sum of the 16 PAHs (µg/L)
Roulepur	4,9
Micropolluants routiers – site 1	1,99
Micropolluants routiers – site 2	1,29
Micropolluants routiers – site 3	1,67

PAHs concentration in Roulepur is recorded higher than in “Micropolluants routiers”. The Roulepur value is found to be similar to the predicted range for major roads [8] [11].

Fluoranthene and Pyrene are the PAHs species with the highest concentrations in both projects. In Roulepur, Chrysene, BbF and BPer are then the PAHs most present whereas in “Micropolluants routiers”, it is Acyl and Phe.

In Roulepur, the partitioning shows that only three PAHs were quantified in the dissolved phase for all events: Phen, Fluo and Pyr with a tendency to be were mostly particulate with a median proportion of particulate phase of respectively 93, 98 and 99%. In “Micropolluants routiers”, a large inter-site variability can be observed in the partitioning. In site 1, only Acenaphthylene is mostly dissolved whereas in site 2, Dibenzo(ah)anthracene, Acenaphthene and Fluorene are mostly dissolved (with a dissolved fraction superior to 50%) and in site 3, most PAHs are dissolved with a mean partitioning of 70% for all 16 PAHs.

In both projects, PAH were determined as both pyrogenic and oil origins, related to the Phen/A and Fluo/pyr ratio indicator analysis.

7 PAHs (Nap, A, Fluo, BbF, BkF, BaP, BPer) are associated to an EQS by the WFD. As information, these PAHs concentration in the runoff were compared to the environmental limits. The following tab summarized the frequency of the EQS excess for PAHs.

Tab 9. Frequency of EQS excess for PAHs

	100%	In between	0%
Roulepur	Fluo, BaP	A, BbF, BkF, BPer	Nap
Micropolluants routiers		A (between 10% and 20% of the samples) Fluo (between 35-100% of the samples. For site 1, the EQS is always exceeded) BaP, BbF, BkF, BPer (> 60% of the samples)	Nap

8.2.4.5 Bisphenol-A and alkylphenols

- Bisphenol-A

Median BPA concentrations were around 0.1-0.4µg/L for Roulepur, site 1, site 2 and site 3 of "Micropolluants routiers" respectively. In "Micropolluants routiers", BPA was only measured in the dissolved fraction (filtered sample). In Roulepur, it was measured both in the particulate and the dissolved fractions but it was found to be mostly dissolved, with a median dissolved proportion of 95%. BPA concentrations measured are inferior to the ones usually observed in road runoffs [12] [13]

- Alkylphenols

The following tab shows the species quantified and median concentrations in both projects. In site 3 of Micropolluants routiers, alkylphenols were never quantified. And in sites 1 and 2, several components were never quantified (NP_1EO, NP_2EO, OP_1EO, OP_2EO) whereas they were all quantified in Roulepur. It also has to be noted considerable concentration difference regarding NP concentration between both projects (4 orders of magnitude).

Tab 10. Results of the alkylphenols analysis

		Nonylphenols	Octylphenols
Roulepur	Quantification	NP, NP_1EO, NP_2EO, NP_1EC	OP, OP_2EO and OP_1EO (OP_1EO was quantified in only 42% of the samples)
	Median concentration	NP: 1647 µg/L	OP: 0.43 µg/L
Micropolluants routiers Site 1	Quantification	NP: in 80% of the samples NP_1EO and NP_2EO never quantified	OP: in 40% of the samples OP_1EO and OP_2EO never quantified
	Median concentration	NP: 0.6µg/L	OP: 0.1 µg/L
Micropolluants routiers Site 2	Quantification	NP: in 25% of the samples NP_1EO and NP_2EO never quantified	OP: in 25% of the samples OP_1EO and OP_2EO never quantified
	Median concentration	NP: 0.1 µg/L	OP: 0.1 µg/L
Micropolluants routiers Site 3	Quantification	Never quantified	Never quantified
	Median concentration	-	-

The partitioning shows that in Roulepur, alkylphenols were intermediate between dissolved and particulate phase. In “Micropolluants routiers”, NP is mostly particulate with a fraction at more than 80% in site 1. OP is distributed between particulate and dissolved in site 1 but mostly dissolved in site 2.

In Roulepur, NP and OP concentrations were systematically superior to their EQS. In “Micropolluants routiers”, OP was also always superior to its EQS in both sites but NP was exceeding the EQS in 70% of the samples for site 1 and 10% of the samples for site 2.

8.2.4.6 Phthalates

In Roulepur, six phthalates were analysed (see Appendices 1). In “Micropolluants routiers”, only DEHP and DEP were analysed.

The median concentration of DEHP in Roulepur is 14 µg/L, in the same order of range as other values for urban and road runoff [8]. In “Micropolluants routiers”, the median concentration of DEHP is lower, around 3 µg/L for sites 1 and 2. It was never quantified in site 3.

It was observed that DEHP is mostly particulate in both projects and EQS for DEHP is always exceeded.

DEP was only quantified in 33% of the “Micropolluants routiers” site 3 samples. The concentration measured in the samples is equal to the concentration in the blank sample hence, the consequence of the road pollution on this parameter cannot be assessed.

8.2.4.7 Ethers and BTEX

Ethers (MTBE, PBDE, BDE) and BTEX (Benzene, Toluene, Ethylbenzene, Xylene) were only analysed in “Micropolluants routiers” project.

Ethers concentration were lower to the limit of quantification for all samples, regardless of the site. For BTEX, only toluene occurred in two samples of site 3, well below the French regulations. [15]

8.2.5 Classification of pollutants

In “Micropolluants routiers” project, it has been suggested to classify pollutants, according local data, regarding stakes to environment protection by considering both occurrence and comparison to the EQS. It leads to 5 groups, defined as follow, to classify pollutants according local data:

- Group 0: substance without an EQS but quantified or global parameters used to characterize pollution;
- Group 1: substance not quantified;
- Group 2: substance measured with concentrations inferior to the EQS-AA;
- Group 3: substance measured with a concentration between the EQS-AA and the EQS-MAC;
- Group 4: substance measured with a concentration superior to the EQS-MAC.

It is then advised to focus on the pollutants from groups 0, 3 and 4 as they should impact the most the environment. It is important to note that this distribution is not exhaustive (continuous evolution of emerging pollutants), depends greatly on the local context and so should be done based on local data. As an illustration of the classification method, Tab 13 summarises a possible classification obtained from Roulepur and “Micropolluants routiers” project data.

Tab 11. Classification of the pollutants

<table>
<tr><th>Group 0</th><th>Group 1</th><th>Group 2</th><th>Group 3</th><th>Group 4</th></tr>
<tr><th>No EQS but occurrence</th><th>Never quantified (C < LQ)</th><th>C<EQS-AA</th><th>EQS-AA<C<EQS-MAC</th><th>EQS-MAC<C</th></tr>
<tr>
<td rowspan="2">Strontium
Aluminium
Total petroleum hydrocarbon

Acenaphthene
Acenaphthylene
Benzo(a)anthracene
Chrysene
Dibenzo (a, h) anthracene
Fluorene
Indeno (1,2,3-c, d) pyrene
Phenanthrene
Pyrene

Bisphenol A

Iron
Manganese
Sodium
Potassium
Magnesium
Calcium
Silicon</td>
<td rowspan="2">Octylphenols monoethoxylate and diethoxylate

Mercure

MTBE
BDE
PBDE
Benzene
Ethylbenzene
Xylene

Nonylphenols monoethoxylate and diethoxylate*</td>
<td rowspan="2">Molybdenum

Naphthalene

Bore

Toluene

Barium**
Lead**
Vanadium**
Nickel**
Cadmium**
Nonylphenols monoethoxylate and diethoxylate**</td>
<td>Para nonylphenol

Antimony

Arsenic**</td>
<td>Anthracene
Benzo(b)fluoranthene
Benzo(ghi)perylene
Benzo(k)fluoranthene
Benzo(a)pyrene
Fluoranthene

Arsenic*
Cadmium*
Lead*</td>
</tr>
<tr>
<td colspan="2">Titanium***
Zinc***
Copper***

Octylphenols*

DEHP*

Cobalt***

Barium*, ***
Vanadium*, ***</td>
</tr>
</table>

* Results from Micropolluants routiers, ** Result from Roulepur, *** No EQS-MAC

Analysed only in dans Roulepur

Analysed only in Micropolluants routiers

Same classification for Roulepur and Micropolluants routiers

Different classification between Roulepur and Micropolluants routiers

8.3 Conclusion

This synthesis focuses on the characterisation of road runoff pollutants, based on two French projects Roulepur (2014-2020) and "Micropolluants routiers" (2017-2021) results. Different pollutants where analysed in the road runoff as global parameters, inorganic (metals) and organic pollutants (TPH[18], PAH[19], BPA/AP[20], PAE[21], Ethers, BTEX[22])…

Characterisation was done regarding pollutants occurrence, concentrations and fractioning. Fractioning matters to understand pollutants behaviour and to implement pertinent effluent treatment. Also, as indication, measured concentration have been compared to the EQS used to evaluate good ecological status of water bodies (European Frame Work).

As a general matter, concentrations found in Roulepur were often superior to those of Micropolluants routiers project even though catchment area and traffic were lower (< 10% and <50% respectively). One explanation might be Roissy CDG airport's proximity to Roulepur catchment. Indeed, the pollution induced by air traffic might contribute to the atmospheric deposit and be a source of many pollutants similar to the ones produced by the cars and trucks. Moreover, the location near an industrial zone is a source of a dense truck traffic and can contribute to the higher concentrations observed in Roulepur.

A system of classification based on local context and EQS was developed in Micropolluants routiers, to focus action on pollutants that should have the higher impact on environment. It was illustrated for the two projects reviewed here.
It is important to consider the local context, the environment sensitivity and the potential use when characterising road runoffs. It should be kept in mind that pollutants to focus on could be different from one place to another, depending on catchment characteristics, receiving water bodies vulnerability. Also, in a given location, runoff water quality is changing regarding weather conditions and rain events. Finally, pollutants to consider is continuously evolving with changes in practices, regulations, new pollutants investigation and analytical progress.

The pollutants that were studied in these two projects are obviously not exhaustive: choices were made regarding the analytical and financial resources of each project. Thus, in addition to the pollutants studied in these two projects, it can be interesting to analyse other emerging pollutants like microplastics or PFAS for example.

The Rural Roadwater Rescue project focuses on the potential use of roadwater runoff in order to support local water systems. Considering the quality of roadwater runoff, it certainly should be treated before being used. As a consequence, some questions arise and may be worth looking into: which quality for which use? Which kind of treatments? How to implement them? Are there specific according to intended use?

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[18] Total petroleum hydrocarbon

[19] Polycyclic aromatic hydrocarbons

[20] Bisphenol A / Alkylphenols

[21] Phthalates

[22] Benzene, toluene, ethylbenzene, xylene

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8.5 Appendices

Appendices 1 : Parameters considered in the reviewed projects

1. Parameter	Substance	Road micropollutants	Roulepur
Global parameters	pH	■	■
	Electrical conductivity (EC)	■	■
	Turbidity		■
	Total suspended solids (TSS)	■	■
	Total organic carbon	■	■
	Dissolved organic carbon	■	■
	Chemical Oxygen Demand (COD)	■	
	Biological Oxygen Demand (BOD)	■	
	Kjehdal nitrogen (KN)		■
	Ammonium (NH4+)		■
	Nitrite (NO2-)		■
	Nitrate (NO3-)		■
	Phosphorus (P)		■
	Chloride (Cl)	■	
	Phosphate (PO43-)		■
Metals	Arsenic (As)	■	■
	Cadmium (Cd)	■	■
	Chromium (Cr)	■	■
	Copper (Cu)		■
	Nickel (Ni)	■	■
	Mercury (Hg)	■	
	Lead (Pb)	■	■
	Strontium (Sr)	■	
	Vanadium (V)	■	■
	Zinc (Zn)	■	■
	Aluminium (Al)	■	■
	Antimony (Sb)	■	
	Boron (B)	■	
	Iron (Fe)		■
	Manganese (Mn)		■
	Molybdenum (Mo)	■	■
	Strontium (Sr)		■
	Titanium (Ti)	■	■
	Sodium (Na)	■	■
	Potassium (K)		■
	Magnesium (Mg)		■
	Calcium (Ca)		■
	Barium (Ba)	■	■

	Silicon (Si)		
Total petroleum hydrocarbons (TPH)	C10-C40 (TPH)		
Polycyclic aromatic hydrocarbons (PAH)	1-methyl Naphthalene (1MN)		
	2-methyl-Naphthalene (2MN)		
	Acenaphthene (Acen)		
	Acenaphthylene (Acyl)		
	Anthracene (A)		
	Benzo[a]anthracene (BaA)		
	Benzo[a]pyrene (BaP)		
	Benzo[b]fluoranthene (BbF)		
	Benzo[ghi]perylene (BPer)		
	Benzo[k]fluoranthene (BkF)		
	Chrysene (Chry)		
	Coronene (Cor)		
	Dibenzo[ah]anthracene (DahA)		
	Fluoranthene (Fluo)		
	Fluorene (F)		
	Indeno(123-cd] pyrene (IP)		
	Naphthalene (Nap)		
	Phenanthrene (Phe)		
	Pyrene (Pyr)		
Bisphenol -A (BPA) Alkylphenols (AP)	Bisphenol-A (BPA)		
	Para nonylphenol (NP)		
	Nonylphenol monoethoxylate (NP1EO)		
	Nonylphenol diethoxylate (NP2EO)		
	Nonylphenol monocarboxylate (NP1EC)		
	4-tertoctylphenol (OP)		
	Octylphenol monoethoxylate (OP1EO)		
	Octylphenol diethoxylate (OP2EO)		
Phthalates (PAE)	Diethylphtalate (DEP)		
	Dimethyl phthalate (DMP)		
	Diisobutyl phthalate (DiBP)		
	Dibutyl phthalate (DBP)		
	Bis(2-ethylhexyl) phthalate (DEHP)		
	Dinonyl phthalate (DNP)		
Ethers	Methyl tert-butyl ether (MTBE)		
	Polybrominated diphenyl ethers (PBDE)		
	Brominated diphenyl ethers (BDE)		

BTEX	Benzene		
	Toluene		
	Ethylbenzene		
	Xylene		

Appendices 2 : Threshold value for the EQS

Valeurs seuils NQE des substances

Parameter	Substance	NQE *Dissolved phase*	
		AA (µg/L)	MAC (µg/L)
Trace metals	Arsenic (As)	0,83	1,37
	Cadmium (Cd)	0,15 (class 4 water hardness)	-
	Chromium (Cr)	3,4	
	Cobalt (Co)	0,3	
	Copper (Cu)	1	
	Nickel (Ni)	4	34
	Mercury (Hg)	0,047	0,07
	Lead (Pb)	1,2	
	Strontium (Sr)	-	-
	Vanadium (V)	2,5	
	Zinc (Zn)	7,8	
Major irons	Aluminium (Al)	-	-
	Antimony (Sb)	0,6	177
	Boron (B)	218,5	
	Iron (Fe)	-	-
	Manganese (Mn)	-	-
	Molybdenum (Mo)	6,7	
	Titanium (Ti)	2	
	Sodium (Na)	-	-
	Potassium (K)	-	-
	Magnesium (Mg)	-	-
	Calcium (Ca)	-	-
	Barium (Ba)	60	
	Silicon (Si)	-	-
Total petroleum hydrocarbons (TPH)	C10-C40 (TPH)	-	-
Polycyclic aromatic hydrocarbons (PAH)	1-methyl Naphthalene (1MN)	2	130
	2-methyl-Naphthalene (2MN)	2	130
	Acenaphthene (Acen)	-	-
	Acenaphthylene (Acyl)	-	-

	Anthracene (A)	0,1	0,1
	Benzo[a]anthracene (BaA)	-	-
	Benzo[a]pyrene (BaP)	0,00017	0,27
	Benzo[b]fluoranthene (BbF)	-	0,017
	Benzo[ghi]perylene (BPer)		0,0082
	Benzo[k]fluoranthene (BkF)	-	0,017
	Chrysene (Chry)	-	-
	Coronene (Cor)	-	-
	Dibenzo[ah]anthracene (DahA)	-	-
	Fluoranthene (Fluo)	-	-
	Fluorene (F)	-	-
	Indeno(123-cd] pyrene (IP)	-	-
	Naphthalene (Nap)	2	130
	Phenanthrene (Phe)	-	-
	Pyrene (Pyr)	-	-
Bisphenol -A (BPA) Alkylphenols (AP)	Bisphenol-A (BPA)	-	-
	Para nonylphenol (NP)	0,3	2
	Nonylphenol monoethoxylate (NP1EO)	0,3	2
	Nonylphenol diethoxylate (NP2EO)	0,3	2
	Nonylphenol monocarboxylate (NP1EC)	0,3	2
	4-tertoctylphenol (OP)	0,1	-
	Octylphenol monoethoxylate (OP1EO)	0,1	-
	Octylphenol diethoxylate (OP2EO)	0,1	-
Phthalates (PAE)	Diethylphtalate (DEP)	-	-
	Dimethyl phthalate (DMP)	-	-
	Diisobutyl phthalate (DiBP)	-	-
	Dibutyl phthalate (DBP)	-	-
	Bis(2-ethylhexyl) phthalate (DEHP)	1,3	-
	Dinonyl phthalate (DNP)	-	-
Ethers	Methyl tert-butyl ether (MTBE)		
	Polybrominated diphenyl ethers (PBDE)		
	Brominated diphenyl ethers (BDE)		
BTEX	Benzene	10	50
	Toluene	-	-
	Ethylbenzene	-	-
	Xylene	-	-

9 Synthesis of research projects on roadwater in Flandres

9.1 Introduction

To complement the bibliographic research of Cerema in the project Rural Roadwater Rescue, the Vlaamse Milieumaatschappij writes an English summary of previous experiences in studies that investigated road water as source of pollution to the water courses we manage. The road sanitation studies are linked to LIFE Belini in which we aim to implement a treatment infrastructure before end 2026, that mitigates the impact on the IJse valley in Flanders (focus on implementation of a use case), and aims to investigate the possible impact to groundwater infiltration in Brussels (focus on investigation). The micro-plastics study was ongoing simultaneously, but is also shared because of one of its focuses on tyre wear. **References can be found in the original documents of the corresponding studies.**

9.2 Road Water Sanitation study

The study 'Road Water Sanitation; exploration of technological possibilities and case studies' (2018-2019) was commissioned by VMM and carried out by Witteveen+Bos. This study was initiated in response to the determination of the impact road water can have on a watercourse such as the IJse (tributary of the Dijle), where we want to achieve good ecological status in Flanders. The purpose of the study is twofold: characterization of the water quality composition of runoff water from roads (1) and presentation of technological possibilities to mitigate its impact on the watercourse in such a way that it does not jeopardise the objectives for a good ecological status as intended in the Water Framework Directive. The report consists of a literature review and further elaboration of use cases along IJse, Laan and Voer for mitigating the impact from E411, ring around Brussels and E40. This project was carried out and framed within LIFE Belini (an integrated project that focuses on the implementation of the River Basin Management Plan of the Scheldt running from 2016 to 2026). The resulting report (in Dutch) can be downloaded from the VMM website. This is not a binding document, but it does constitute the recommendation from a water management point of view on the water quality aspect in permit applications.

To date, there are a limited number of quality standards for traffic-related pollutants, this mainly focused on discharges from classified businesses e.g. petrol stations, car washes, car depots... Discharge of water from roads is not classified as a business activity. In addition, to date, rainwater is legally considered non-polluted. However, there are mandatory quantitative guidelines towards buffering. The qualitative standards we can compare with are those applicable to surface water (EQS in Water Framework Directive). The measurements to characterize the road water were determined in the 'discharge water'. Where they exist, the results were also compared with company standards for hazardous and priority substances (IC-GS). Parameters analyzed in road water PAH's, heavy metals (dissoved and particulate phase), general parameters (pH, conductivity, oxygen, N, P, BOD, COD, TSS), total petroleum hydrocarbon. Also sediment samples were analyzed. A detailed analyses of samples and comparison to ecological quality standards can be found via this **table**.

9.3 Main conclusions

General

1. Water drained from major roads (such as motorways) has been found to be polluted. Until now, this has been classified as non-polluted rainwater under Flemish environmental legislation.
2. In most cases, polluted motorway water is discharged untreated into surface water.

3. A ‘first flush effect’ (= increased runoff after a long period of drought) could not be established

Characterisation of contamination in run-off road water

4. Highway water contains oil, heavy metals, PAHs, de-icing salts and suspended matter, as well as organic pollutants such as nitrogen and phosphorus.
5. Most traffic-related pollutants (except salts) are bound to suspended matter and can be removed from the water based on sedimentation.
6. The most common and problematic heavy metals and poly-aromatic hydrocarbons detected for the case studies in this report are:
    - PAHs: B(a)P, Flu, B(ghi)Pe, B(b)Flu, Pyr, B(k)Flu, Fen
    - Heavy metals: zinc, cobalt, copper, lead, cadmium
7. Elevated concentrations of organic matter (COD, BOD), nitrogen (Nt) and phosphorus (Pt) are also found in the highway water.

Recommendations

8. Decentralised treatment by road side infiltration is recommended as a solution. This limits the presence of pollutants to the top 40 cm, and occasional scraping and processing of the top layer prevents any drawbacks of roadside infiltration in terms of drainage and accumulation of pollutants.
9. If infiltration next to the roadside is not possible, a natural based solution is preferred. In concrete terms, this means an oil separator and pre-sedimentation combined with a buffer and/or infiltration basin, whether or not equipped with planting (helophytes) or activated carbon adsorption.

The existing buffer basin at Bertem as a semi-natural wastewater treatment plant was further investigated. Here we found that for PAH and bound fractions of heavy metals, an average of more than 70 % is removed after sedimentation; and an additional 20 % after reed bedding.

In the in-depth Bachelor thesis (2020) by Elisabeth Mevis, thought was given to the **decision framework** that should be set up that indicates whether or not to start treating the run-off road water. The decision framework should depend on several questions that help in prioritization such as: ‘*Are the roads located in sensitive natural areas, drinking water areas, etc.?*’ , ‘*How many cars per day travel over the road?*’, ‘*Does the road water create a direct or indirect (via a basin, overflow or WWTP) bottleneck for the receiving water body?*’ ‘*How large is the volume and discharge of the receiving water body?*’ As a standards framework, a way of working as, for example, in England could be presupposed: when the standards for hazardous substances (such as Zn, Cd, Cu, Pb, ZS, B(b)Flu, B(ghi)Pe, B(a)P, Flu and/or Pyr) are exceeded in the road water itself (Environment Agency and Transport for London, 2019), a treatment scenario should be linked to it.