Rural Roadwater Rescue

WP 1 Rural_Roadwater_Rescue_Activity

Activity 1.3 Identifying and assessing possible solutions for the use of runoff roadwater water depending on water quality and legal boundaries.

D 1.3.1– Set of possible, integrated, cross-sectoral solutions

Report

Period 3

31.03.2025

1 Introduction

With climate change, extreme periods of both too much water and a shortage of water are getting more frequent. In both situations, roads and especially highways can help in conserving and transporting water. The water of roads is highly polluted. The goal of the RRR-project is to achieve that highways are contributing to solving local water problems in both directions. Cleaning the water is obligatory to make it available for local use.

Within the project, the activity shown here (1.3) is planned to give possible solutions for cleaning. It integrates the work on the collection of experiences and the assessment of the legal framework conditions and further integrates water quality aspects. Possible water reuse and treatment (cleaning) strategies, especially with regards to the territorial framework conditions in the respective regions, are addressed in this deliverable.

The activity fully takes into account the results from activity 1.1 and 1.2. The water quality / treatment (cleaning) challenges are the remaining factor for the preparation of integrated solutions: Outcomes of activities 1 and 2 are brought together to determine action prospects, including nature based solutions for rural roadwater runoff in EU member states. Knowledge on water treatment (cleaning) processes to reach special water qualities will be compared on one hand to the need of water qualities for certain uses and on the other hand to possible local realisation options.

As a result, the existing knowledge of water quality assurance will be further developed and discussed with regards to the existing set of possible solutions and the general strategy and concrete proposals for on-site water quality management.

2 Applied cleaning strategies in the partner countries

Cleaning/ treatment of roadwater already takes place in all partner countries of the RRR-project. Within the RRR-framework "Cleaning" was defined as the 3rd out of 7 basic elements necessary for a possible roadwater utilization and should give ideas about treatment methods applicable before the collected roadwater is further distributed/reused/infiltrated. Techniques are classified as natural, semi-natural, semi-technical and technical solutions and can be either centralized, partially centralized or decentralized:

1. Natural treatment includes natural infiltration via road shoulders or basins and natural (sinking) basins.
2. Semi-Natural treatment includes infiltration installations and artificial sinking basins.
3. Semi-Technical treatment includes grids, oil separators and reed systems.
4. Technical treatment includes options for instance oxidation processes (OPs), disinfection methods (e.g. chlorination, UV) and membrane filtration processes (e.g. ultrafiltration, nanofiltration, reverse osmosis) and many others.

During Period 1, information about existing cleaning strategies for roadwater were collected within Deliverable 1.1.1 and 1.1.3. Table 1 summarizes all measures currently undertaken in the partner countries considering the whole road water chain from prevention to use.

Table 1 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
Distribution	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

Answers from the Questionnaire (Deliverable 1.1.3) and gathered knowledge and data from the four partner countries for Deliverable 1.1.1 indicate that there are already existing measures for cleaning of collected roadwater in Germany, France, Belgium and the Netherlands. However, the methodological focus and also the frequency of applications differs in the four countries.

In **Germany**, all run-off water from highways must be cleaned to qualities that do not negatively impact the receiving waters they are released to. Thus, infiltration into water protection zones is not allowed without appropriate water treatment. Mostly this is done by little treatment plants next to the highways that consist of oil separation, grids and sedimentation basins. Shoulder infiltration is almost never performed along German highways. So, the focus here is on semi-natural and semi-technical treatment strategies.

In **France**, they also make use of semi-natural and semi-technical approaches to clean roadwater, but also the use of grassed ditches is commonly recommended and applied for reasons of costs. Also natural infiltration of stormwater along existing highways could occur, and is becoming increasingly common for new road infrastructure projects, in particular those located near cities.

In the **Netherlands**, shoulder infiltration is the most common and preferred way to clean water coming from national highways. 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. Collected runoff is then directed through oil separators that remove hydrocarbons.

In **Flanders** (Belgium), it is prohibited to construct infiltration facilities in protection zones for groundwater to minimize the risks of contamination of drinking water wells. Outside the drinking water protection zones, it is technically no problem to infiltrate non-contaminated rainwater from the road into the soil. Especially in new projects of road renovation, the shift to infiltration next to the road side is more often made nowadays. When this is not possible, other systems are considered, such as semi-technical treatment by sedimentation basins and infiltration beds.

The given information are summarized graphically in Figure 1.

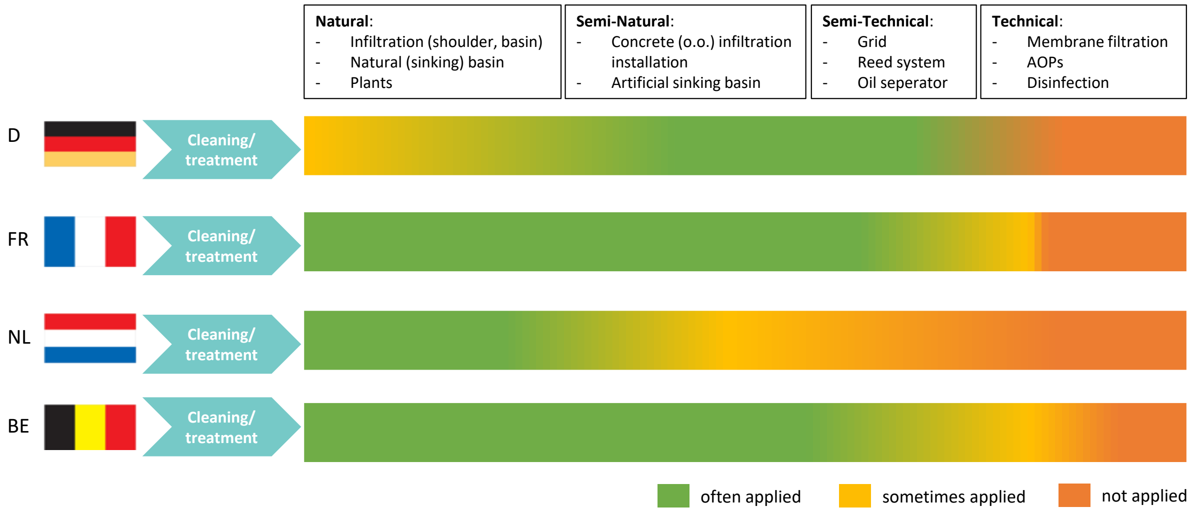

Figure 1 Degree of roadwater cleaning/ treatment methods in the four partner countries.

To conclude, there are **no unique EU-wide regulations or recommendations how to deal with polluted water coming from roads.** All four RRR-partner countries have their own solutions and applications with different focusses on rather natural or technical treatment approaches, of course also depending on the run-off water volumes the treatment facilities are usually receiving. Also the management level of roadwater treatment varies among the countries, sometimes being more centralised and sometimes more on a decentralised local level. This shows the importance of collecting the existing reuse and treatment strategies and compare them for their purpose, efficiency and applicability. This could enable the RRR-team to suggest possible solutions for EU-wide centralised roadwater treatment guidelines for an optimized roadwater management important for stormwater protection and future fresh water availabilities.

3 Existing legal boundaries in the partner countries

The European Union (EU) has established a comprehensive framework of water-related legislation that sets out common standards and objectives to ensure a sustainable use and protection of water resources. This framework serves as a powerful driver for national water policies. The implementation of European water legislation in national policy involves a degree of flexibility that allows Member

States to adapt the directives to their country specific context while still achieving the overarching aims set by the EU. Member States are allowed to adapt national implementation slightly differently, but as a minimum, the EU aims have to be fulfilled.

The methods applied to clean roadwater are strongly dependent on the purpose the water should be used for. The water must fulfill different kinds of water quality criteria, which are mostly described in country specific regulations. For agricultural purposes, currently water users/water utilities can do reduced water treatment (e.g. only sand filtration). However, they do not use roadwater yet but e.g. river water. The existing treatment chains must therefore be transformed for the usage of roadwater, where a detailed differentiation of the treatments must be done, according to the required water quality per type of usage (e.g. car washing requires different water quality standards compared to irrigation of freshly eaten vegetables). Therefore, the initial step is to collect all relevant existing legal boundaries that regulate the usage of water of a special quality. As it is already described in detail in Deliverable 1.2.1, there are several regulations in the NWE countries (national and EU-policies), where also parameters are given, that must be analysed as quality criteria of the water types and limit values of these that must not be exaggerated. Depending on the roadwater reuse purpose (i.e. deliver to surface water, infiltration to ground water, human use for irrigation (agriculture) or other domestic/industrial usage), different European legislations will apply. In Figure 2, the framework of different policies involved depending on the route of road water to natural ecosystems (1) or human usage (2) is roughly linked. The initial prevention step (preventing pollution to end up in the roadwater) is also taken into account.

When it comes to usage of roadwater within the human water cycle, different directives for water quality could play a role and must be taken into account, e.g for agricultural use, industrial processes or usage in households. In Europe, water quality standards are defined for drinking water (water for human consumption) [1], reuse water (irrigation) [2] and bathing water [3], each with different limit values for fecal indicator bacteria (*E. coli* and *Enterococci*). These limit values are shown in Figure 3. The basis of EU water legislation is the Water Framework Directive (WFD) [5], which establishes a holistic approach to water management, aiming to achieve ‘good status’ for all EU waters, including rivers, lakes, groundwaters, and coastal waters.

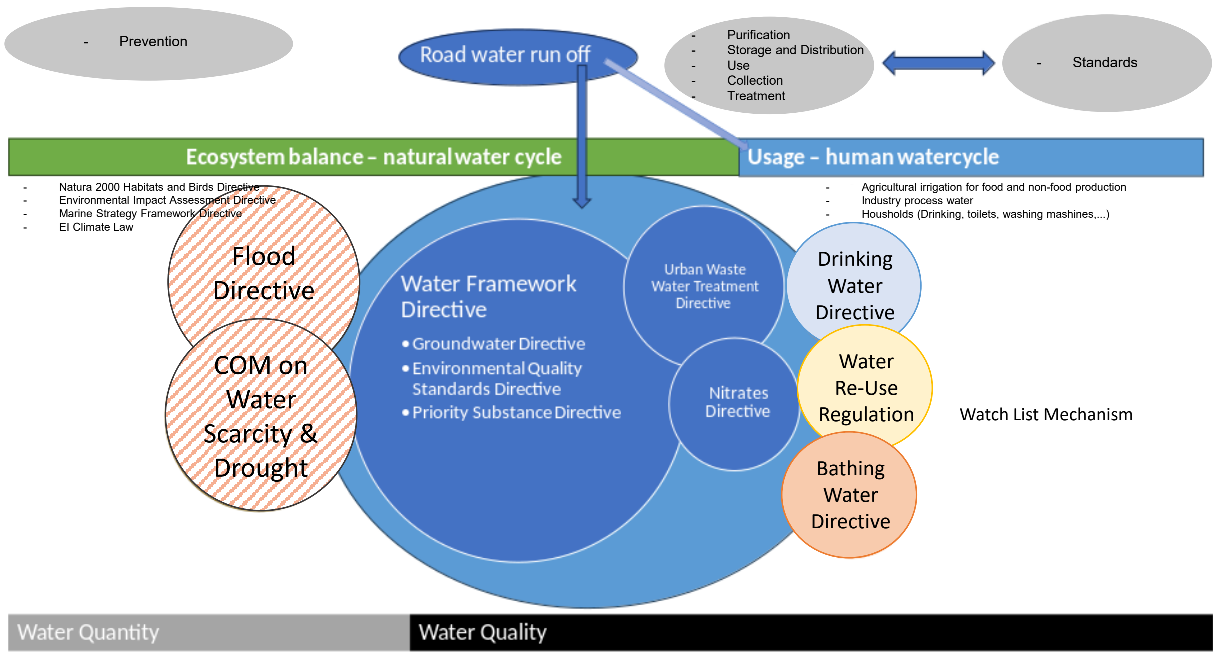

Figure 2 Framework of different policies involved for water quality and quantity; within both the natural and human cycle that might be relevant for roadwater management depending on the "usage" intended. (author's own analysis) – Adopted from RRR Deliverable 1.2.1.

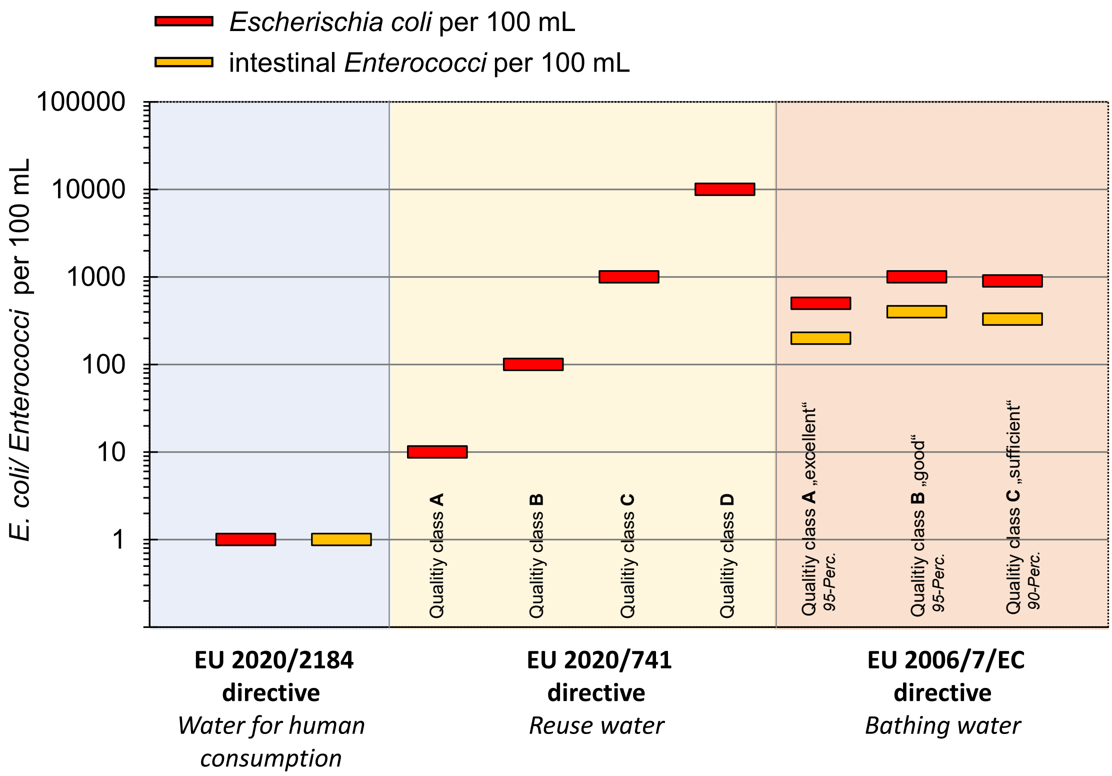

Figure 3 Limit values for fecal indicator bacteria E. coli and Enterococci within the three EU directives for drinking water (water for human consumption), reuse water (irrigation water) and bathing water.

In some of the directives, also chemical limit values are given and then have to be taken into account. Details about chemical parameters and their limit values are given in RRR Deliverable 1.2.1. There, pollutants for which there is a clear link with traffic and roads (cf. D 1.1.1, Chapter 8, Section 8.2.3.1 Origin of pollutants in road runoff) have been included. Implementation of standards can be different between countries (related to differences in translation of EU regulations into national legislation) and within countries (i.e. depending on the vulnerability of the receiving river). However, by complying with the microbiological limit values, the main safety of reusing the roadwater can be ensured. The existing limit values within the EU directives are based on fundamental scientific research and national regulations and should be adapted to the reuse cases for roadwater, if the roadwater enters the human water cycle.

To implement a new reuse of roadwater not only the legal boundaries must be known and considered, but also local authorities must be convinced that the innovative use is an economic, sustainable and valuable approach. This mostly can only be realized, if a solid argumentation can be delivered with the idea. Considering the following points could help to build such a consequent argumentation:

- ➔ Refer to existing solutions in other countries. Especially in other countries, that have to deal with extreme weather events since longer times, similar solutions have maybe already been applied and proven to be very useful and important, giving benefits to both, biodiversity and society.
- ➔ Check if the roadwater use is a cheaper alternative to the standard use of tap water in drinking water quality. Especially with droughts getting more frequent, the drinking water price is supposed to increase.
- ➔ Make sure you are aware of the quality standards the water you want to use roadwater for are well known and that chemical and/or biological analyses of the water that are necessary can be ensured.
- ➔ Present your ideas and action plans to communities and convince them to increase the pressure on authorities and stakeholders.

4 Possible solutions for the cleaning and reuse of roadwater

4.1 Highway design

The design of future highways can be an important factor for making roadwater easier accessible for collecting, cleaning and subsequently reusing it. In some countries, like the RRR partner country Germany, special gully systems are already established on highways, to allow a good collection even on modern large-pored noise reducing asphalts. Here, the bigger pores allow the water to be slightly seeped into the asphalt (currently around 5 to 6 cm deep), also giving it a higher water capacity in case of heavy weather. Drainages are then placed below the road surface to collect the seeped water (Figure 4).

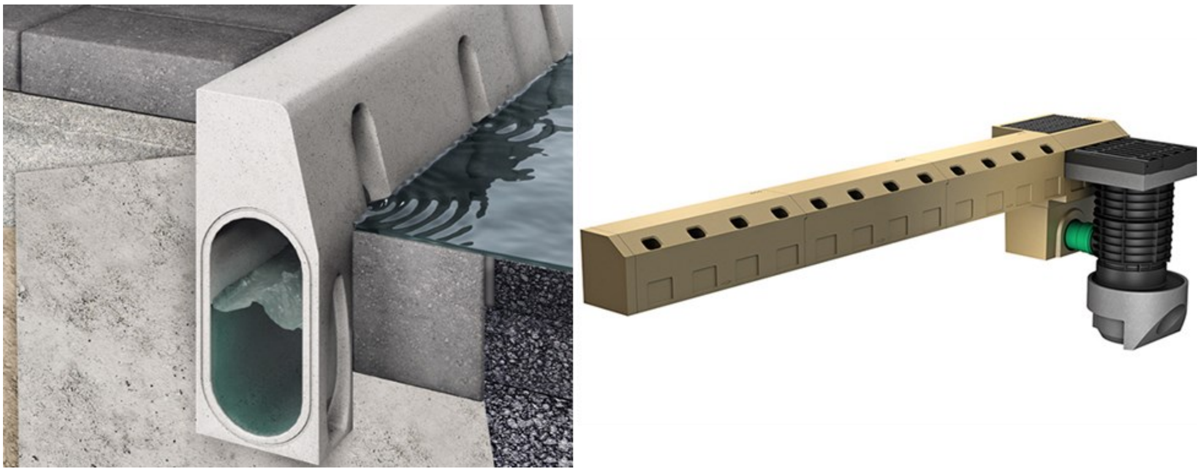

Figure 4 Optimized collection of surface and seeped water in large-pored noise reducing asphalts, as applied for example in Germany.

There are various other methods to design highways with regard to collecting road runoff water, which is vital for preventing accumulating roadwater and ensuring safe driving conditions, but also to ensure a subsequent treatment and reuse of it. A preferred way, e.g. in the Netherlands, is an inclined road construction, as shown in Figure 5, to improve water drainage to shoulders or ditches.

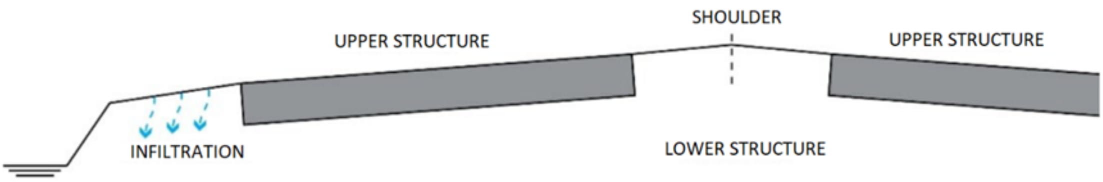

Figure 5 Netherlands : Shoulder infiltration (cross-section).

Besides the highway or road designs that are already applied, there is also a high interest in innovative technologies focusing on future “smart roads” [4]. Within a smart road system, all the components are sources of a large amount of useful data that is generated in a short time by sensor systems, like for instance the infrastructures’ condition, traffic status or even water amounts. By automatised data evaluations, the roads might be even able to adapt to circumstances in future scenarios. Also gaining energy with roads is an important innovation to be implemented in the near future. For instance “solar roads”, which can generate power from the sun, have gained popularity in recent years as a smart alternative to the traditional asphalt roads dominating the scene around the world [6]. They would produce clean and sustainable energy, that also could be directly used for advanced roadwater treatment needed for high quality water for purposes of e.g. agricultural irrigation.

Plastic roads is another innovative answer to the long due problems of traditional asphalt and concrete roads [6]. They could consist of light, prefabricated, modular and hollow road structure made from recycled plastics with a life expectancy up to three times as long as the traditional asphalt pavement. It is prebuilt and can be easily installed on site, preventing excessive disruption to the public or traffic operations. Hollow spaces within the plastic pavement can serve as temporary storage for storm water preventing flooding during extreme precipitations.

Ideas about permeable pavement, defined as a type of pavement with several permeable layers that has the ability to store stormwater until it infiltrates through the subgrade soil and can function as a conventional pavement to carry specific traffic load and speed, was presented by the National Center for Sustainable Transportation, California [7]. Even if such permeable roads would come with benefits like noise reduction, stormwater runoff volume management, an increase in water quality and improvement in thermal performance and urban heat island impact, they would also bring several problems that have to be addressed like extra cost, moisture damage and groundwater contamination. However, Kayhanian et al. [7] summarize several studies in their paper, concluding that permeable pavements, when constructed well and when they have received regular maintenance, will have the ability to reduce peak runoff flow rates and infiltrate a significant fraction of runoff volume.

To conclude, including thoughts and ideas about an innovative highway design into future plans on roadwater cleaning/treatment strategies is worthwhile, as it can have a huge influence on the water quality and accessibility for treatment and reuse.

4.2 Roadwater reuse opportunities

In many industrial, municipal and private facilities, water of very high quality is currently used for applications, where water of lower quality would be sufficient as well. To treat water to drinking water quality standards requires a lot of financial and energetic resources. Thus, it is highly recommended to check, whether a local reuse of roadwater would be an option for the purpose it is required for.

Roads and especially federal highways in NWE are always very close to industrial, municipal or private facilities, which could make use of the roadwater, often automatically collected by existing gullies.

These are potential uses among many other opportunities not considered here. Several categories could be identified to be useful when evaluating if roadwater could have advantages over the water usually utilised for a certain purpose.

In Table 3 some suggestions are listed, where the reuse of roadwater could be considered. Depending on the use, different water quality standards must be fulfilled by law. For some uses also no standards are required and roadwater could be just used directly. The different conditions are characterized by the colours green (roadwater can be used directly without analyses or treatment) to red (drinking water quality required and thus analyses and treatments are necessary), giving first insights into how easy it would be to replace water for a specific purpose with water from roads. The water quality categories were defined as listed in Table 2:

Table 2 Water quality categories that indicate how low a water quality could be for a certain reuse and thus, how low the effort would be to make use of it. The categories 1, 2 and 3 are derived from the EU directives as shown in Figure 3.

Water quality requirements				
low quality	**Water type**	**Definition**	**Regulation (EU)**	**Thresholds**
5	Wastewater	untreated greywater		
4	Surface Water	surface waters such as rivers or lakes	EU regulation 2000/60/EC (2000)	
3	Bathing water (Quality B)	not for consumption but direct contact to human body	EU regulation 2006/7/EG (2006)	≤ 1000 E. coli/ 100 mL; ≤ 400 intestinal Enterococci/ 100 mL
2	Reuse Water (Quality A)	no consumption but direct contact to human consumabales (food)	EU regulation 2020/741 (2020)	≤ 10 E. coli/ 100 mL; ≤ 10 mg/L BSB5; ≤ 10 mg/L TSS; ≤ 5 NTU turbidity
1	Drinking Water	water intended for human consumption	EU regulation 2020/2184 (2020)	0 E. coli/ 100 mL; 0 intestinal Enterococci/ 100 mL; thresholds for further hydrochemical parameters
high quality				

Table 3 Roadwater reuse opportunities and their ranking for required water qualities and other relevant factors.

Opportunities to re-use roadwater:	Water quality requirements	Additional space requirements	Infrastructural demand	Implemen-tation	Number of users	Water quantity	Sum
Industrial water utilization (e.g. industrial cooling, greenhouse warming)	5	4	5	3	4	5	30
Firefighting	5	3	3	4	5	5	29
Road cooling → prolonging road lifetime	5	4	2	3	3	4	25
Particle extraction to make e.g. new tires	5	1	3	1	2	5	21
Air washing along highways	5	3	2	1	2	3	20
Groundwater infiltration	4	5	5	5	5[2)]	4	32
Forestry	4	3	5	4	5	5	30
Re-weat of moors	4	5	4	5	5	5	29
Recharge dried out rivers	4	5	4	5	5	5	29
Concrete production	4[1)]	3	5	4	4	5	29
Industrial plant cleaning	4	4	5	5	3	4	29
Toilet flushing (private, highway petrol stations,...)	4	3	5	3	5	5	29
Cementries	4	4	4	3	4	3	26
WWTP network cleaning	4	3	3	4	3	5	26
Gardening (private gardens, green streets)	3	5	5	4	5	5	31
Carwash	3	4	4	5	3	3	26
Paper recycling	3[1)]	3	5	3	3	3	24
Road cleaning	3	3	3	3	3	3	22
Industrial tool cleaning	3	3	4	3	2	3	22
Sports facilities (golf gardens,..)	3	3	3	2	3	2	20
Agriculture: eaten crops, vegetables, fruits	2	4	5	4	5	5	29

[1)] sometimes chemical requirements
[2)] used by nature and thus by everybody

Legend ranking:

Additional space requirements	low	5	4	3	2	1	high
Infrastructural demand	constant demand	5	4	3	2	1	seasonal, weather dependend demand
Implementation	easy	5	4	3	2	1	difficult
Number of users	high	5	4	3	2	1	low
Water quantity	high, flexible	5	4	3	2	1	low, unflexible

Definitions	
Water quality	Water quality required for the specific roadwater use
Additional space requirements	Space that has to be created additionally to the already existing infrastructure of water reservoir or transportation
Infrastructural demand	Frequency of demand for the special roadwater use
Implementation	Feasibility of realisation of the special roadwater use
Number of users	Number of users who could profit from the use
Water quantity	Amount of water, a system can handle and flexibility torwards varying amounts of water

Roadwater reuse could be easily applied (1) if an infrastructure is already partly given (e.g. if water transportation and storages are already existing but currently water of higher quality is used) and (2) if the roadwater could be directly used without a need of analyses or treatment, which is indicated in Table 3 by a water quality requirement 5 (green).

Water quality 5 (green):

No microbiological or chemical limits are needed. For instance, roadwater could be directly used for industrial cooling, firefighting, road cooling and others.

Water quality 4 (light green):

For some reuse cases directly influencing the surrounding environment, like forestry, ground water infiltration, road cleaning or WWTP network cleaning, a user would need to make sure, that the roadwater used will not harm the environment. Therefore, at least analyses of the roadwater would be necessary and maybe some basic cleaning or dilution. For the rehydration of moors, there is already a project example existing in Germany, where it is checked, whether roadwater can be used to moisten a moor (reweat moor). There are only subordinate water quality requirements. This roadwater reuse has the advantage of revitalisation of a sensible ecosystem and at the same time it promotes decarbonisation of the exhaust polluted air, as moors are effective CO_2 storages. The rehydration or preservation of the existence of rivers or canals could also be a feasible and realistic reuse of roadwater. Rivers, like the exemplary river Erft in West Germany, might almost dry up when drainage pumps of the close-by open-cast lignite mine no longer supplies water. Since the river water is strongly needed for industrial cooling and for agricultural irrigation along the Erft, more thoughts should be given to this reuse strategy.

Even if a roadwater reuse without any or without to much treatment seems applicable for certain types of use cases, it is possible, that there are other restrictions or regulations in different NWE countries, that give further quality requirements. For instance, in France it is currently discussed, if pathogens could be of concern for e.g. road cleaning uses and if these uses therefore harbour risks for road workers, so at least bathing water quality should be considered. For the production of concrete, there is the NF EN 1008 norm, indicating that wastewaters are not suitable for this use. Salted and brackish water could only be used for a certain type of concrete. In contrast, surface or ground waters can be suitable, but have to be submitted to preliminary chemical tests.

It must be noted, that the category “additional space requirements” is strongly depending on the existing infrastructure. If, for example, buffer tanks for firefighting water are already existing, they can easily be used and no additional space would be required. For road cooling, an idea could be to install buffer tanks below roads, so no additional space would be required next to roads. This could additionally lead to evaporation and condensation in the buffer tanks in summer and thus, to road cooling effects. For such purposes, still high infrastructural effort has to be undertaken, which all in all leads to a lower practicability even if untreated roadwater could be used here.

However, also uses with higher water quality demands could be considered. In that case, water analyses and water treatment would be needed. Within the specific EU water regulations, microbiological and partly chemical limits are defined that must be fulfilled for a specific water use. The EU regulations for bathing water, irrigation water and drinking water with the defined microbiological limits are shown in Figure 3 and their use for classification in Table 3 is shown in Table 2.

The definitions for the higher water quality classes have been chosen as follows:

Water quality class 3 (yellow):

In the bathing water directive [3], three different qualities are defined for bathing water indicating if a bathing water is of sufficient (C), good (B) or excellent (A) quality. Based on long-term experiences and expertise of the RRR-consortium in the water sector, it should be recommended to achieve minimum quality B (≤ 1000 *E. coli*/ 100 mL; ≤ 400 intestinal *Enterococci*/100 mL) for roadwater reuses such as gardening, watering of sport facilities, carwash or industrial tool cleaning, since a close contact of user and the used water is unavoidable and infection risks must be reduced.

Water quality class 2 (orange):

If the roadwater is planned to be reused for agriculture/ irrigation of eaten crops, vegetable, or fruits, the water must be of even higher quality, since the infection risk is increased if grown food is consumed directly. Here, the EU gives limits of ≤ 10 *E. coli*/ 100 mL; ≤ 10 mg/L BSB_5; ≤ 10 mg/L TSS; ≤ 5 NTU turbidity in the directive for water reuse and irrigation [2].

Water quality class 1 (red):

This means drinking water quality. Normally, the efforts to treat roadwater runoff to drinking water quality are much too high to reach a competitive price. Therefore, in Table 3, no reuse with water quality class 1 is listed.

All in all, most of the possible roadwater reuse options do not require high water quality. As perfectly treated drinking water is used for several applications listed in Table 3, even if its quality (according to the EU drinking water directive [1]) is not required, it will be of high relevance to evaluate the existing infrastructure in industries, municipalities and private households on the possibilities of using roadwater as a sustainable alternative.

4.3 Road-water treatment methods

4.3.1 General remarks

There are many ways to reuse water from roads. Roadwater is usually contaminated with particles, dissolved hydrocarbons, heavy metals and other materials, that are spread from tyre wear, accidents and wastes. Moreover, as it is in contact with wastes on the roads and on the shoulders next to roads, it will normally be contaminated microbiologically. Therefore, it is of high importance to be aware of the quality standards to be taken into account for a specific use of such water. The roadwater reuses listed in Table 3 were ranked according to their water quality recommendations. That means, that all uses with water quality requirements that are not green (high quality, low number), i. e. lower than 5, could require some treatment prior to their use.

In the following subchapters, treatment methods are listed, that could be used to reach an optimized water quality. These subchapters are sorted according the different treatment classifications as described before (natural solutions, semi-natural solutions, semi-technical solutions and technical solutions), where semi-natural and semi-technical solutions are taken together as the differences are only minimal.

Also here, a ranking by different categories such as installation costs, maintenance costs, personnel requirements, robustness, material requirements, applicability, water throughput and space needed was performed to visualize the applicability of a treatment method for water users. Table 4 gives definitions of these categories and Table 5 gives the indication of the numbers used in the ranking for each category.

It must be noted, that the ranking is based on experiences and expertise of the RRR-consortium and numbers should not be interpreted as absolute and quantitative. The different treatment methods have been ranked relatively to give indications on how easy, cheap, robust, etc. a treatment method can be and thus offers assistance in choosing an appropriate strategy, when roadwater treatment is required.

Table 4 Definitions of water treatment method ranking categories.

Definitions	
Installation costs	Costs that must be considered for the installation of the treatment method itself
Maintenance costs	Costs that must be considered for the maintainance of the treatment method (including personell costs)
Personnel requirements	Includes personnel costs and requirements of specialists/engineers/...
Robustness	Gives indication of the durability of a treatment method
Material requirements	Gives indication on how expensive or rare materials are, that are required for construction
Applicability	Gives indication on how easy an installation and operation can be realized
Water throughput	Amount of water that can be treated in a certain time and adjustability to varying water amounts
Space needed	Space that is needed to construct the treatment plant or the store untreated and treated water

Table 5 Ranking indications of water treatment method categories.

Installation costs	very cheap	5	4	3	2	1	very expensive
Maintenance costs	very cheap	5	4	3	2	1	very expensive
Personnel requirements	very low demand	5	4	3	2	1	very high demand
Robustness	very robust	5	4	3	2	1	very vulnerable
Material requirements	conventional, easy available	5	4	3	2	1	very special, rare
Applicability	easily installable	5	4	3	2	1	complicated
Water throughput	high and/or flexible	5	4	3	2	1	low and/or fixed
Space needed	very little	5	4	3	2	1	very high

4.3.2 Natural solutions

Natural solutions imply mainly nature based treatment methods, such as shoulder infiltration, natural sinking basins or plant systems as described in Table 6. Still, all of these solutions can be ranked with the given categories, since an implementation and maintenance of a working system is mostly required, what means the solutions are indeed nature based but still artificially constructed or a complementation to naturally existing formations. In most of the NWE countries, these are the methods commonly applied, together with semi-natural and semi-technical methods to treat roadwater to a certain quality needed mostly to infiltrate it back to the environment. The Flemish Environmental Society (Vlaamse Milieumaatschappij) is giving an indication on how much % of removal per pollutant can be expected per technique applied (non-technical) in "Sanitation of Roadwater (Sanering Wegwater)" [8].

Table 6 Description and application fields for natural treatment solutions.

Natural treatment	Description	Field of application/Addressed contaminants
Natural infiltration (shoulder, basin)	process by which water on the ground surface enters the soil	particle removal, biodegradation
Natural (sinking) basin	Natural pond to remove suspended particles from the water to be treated	particle removal, biodegradation
Plants	filter that uses helophytes (plants growing with their roots in very wet soil and transport oxygen to their roots) to purify water	particle removal, biodegradation, bio-accumulation

Table 7 Ranking of installation categories for the natural treatment solutions.

Natural treatment	Installation costs	Maintanance costs	Personnel requirements	Robustness	Material requirements	Applicability	Water throughput	Space needed	Sum
Natural infiltration (shoulder, basin)	5	5	4	5	5	5	3	5	37
Natural (sinking) basin	5	4	5	5	5	5	4	3	36
Plants	5	4	5	4	5	5	4	4	36

All of the listed natural solutions in Table 6 and Table 7, including natural shoulder or basin infiltration, natural sinking basins and plants, would be quite easy to install and to maintain. None of them causes strong interference with nature and mostly basins have to be cleaned or plants have to be removed only once within 10-20 years. However, sometimes the capacity of such natural tanks could be too low for heavy rain events and no constructions to regulate the water amounts are existent for these solutions. Moreover, the cleaning performance is mainly reduced to particle removal or partial removal of organic substances through naturally occurring biodegradation processes. Plants could be used, if special contaminants are known to be present, that could be bioaccumulated by the plants. However, the use is quite specific.

To conclude, these solutions are relatively easy to install and to handle. This is why they are already often applied in many of the NWE countries as shown in Figure 1. Still, it has to be investigated, if the cleaning efficiency is sufficient for a contaminated water and if surrounding nature will not be harmed by an accumulation of contaminants and especially regarding higher frequencies of more extreme weather events in the near future, perhaps alternative and more technical solutions have to be considered.

4.3.3 Semi-Natural / Semi-Technical Solutions

Semi-natural and semi-technical solutions imply treatment methods that are artificial constructions, but often complement natural solutions and do not need external energy.

Often, artificial sinking basins are constructed from concrete next to roads and water cleaning is improved by grids and oil separators.

Table 8 Description and application fields for semi-natural / semi-technical treatment solutions.

Semi-Natural /Semi-Technical treatment	Description	Field of application/Addressed contaminants
Artificial sinking basin	Artificial pond to remove suspended particles from the water to be treated	Particle removal, biodegradation
Infiltration installation	targeted installation of artificially applied soil material for water infiltration	Particle removal, biodegradation
Grids	Sieve to remove rough materials from waters	Particle removal
Reed systems	combines aerobic and anaerobic decomposition processes in a 1.0 m thick soil or substratum layer	Biodegradation, bioaccumulation
Oil Separators	device designed to separate gross amounts of oil and suspended solids	Oil removal (on the top layer)

Table 9 Ranking of installation categories for the semi-natural and semi-technical treatment solutions.

Semi-Natural & Semi-Technical treatment	Installation costs	Maintanance costs	Personnel requirements	Robustness	Material requirements	Applicability	Water throughput	Space needed	Sum
Artificial sinking basin	4	4	5	5	3	5	5	3	**34**
Infiltration installation	4	4	4	5	4	5	4	4	**34**
Grids	4	3	3	4	3	5	5	5	**32**
Reed systems	4	3	4	4	4	5	4	4	**32**
Oil Separators	4	4	3	4	3	5	5	4	**32**

All of the solutions given in Table 8 and Table 9 have of course slightly increased installation, maintenance and personnel costs compared to completely natural solutions, but they also offer an increased treatment efficiency without consuming high amounts of external energy. Sometimes collected water has to be pumped to the artificial basins, but only temporarily. Artificial sinking basins have the opportunity, compared to natural sinking basins, that they are constructed from concrete and mostly an infiltration is avoided or directed to a certain area, when complemented by an infiltration installation. The maintenance and space needed, as well as the robustness is very comparable to the natural basin when it has been constructed. Grids and oil separators are very simple installations that do not need any external energy sources, as they are simply mechanically “filtering” the water. Since grids can clog, maintenance can be required more frequently compared to an oil separator, which should be dredged once or twice a year. Also, the maintenance of reed systems is required more often (e.g. mowing or circulate the soil).

Semi-natural and semi-technical solutions can be applied, if an optimization of roadwater qualities is needed, but no high standards as given in the EU regulations for bathing, irrigation and drinking water are required.

4.3.4 Technical Solutions

There is a high variety of technical applications that can be used to optimize water quality. Technical solutions usually need detailed construction and installation planning, as well as external energy for water pumping (sometimes with high pressures) or formation of disinfectants or gas bubbles. Some of these solutions also require lots of space, just like sand filter or aeration tanks.

Of course, most of the solutions listed in the Table 10 and Table 11 have the advantage that they can specifically remove certain contaminants from roadwater and that water can be treated to such a degree of purity that it can be used for almost any purpose.

Table 10 Description and application fields for technical treatment solutions

Technical treatment	Description	Field of application/Addressed contaminants
Rapid sand filters	water flows at about 5 m/h through the filter medium under gravity or under pumped pressure and the floc material is trapped in the sand matrix	Particle removal, biodegradation
Slow sand filters	Sand filters using a complex biofilm that grows naturally on the surface of the sand	Particle removal, biodegradation
Aeration basin	brings water and air in close contact in order to remove dissolved gases and to oxidize dissolved metals, including iron, hydrogen sulfide, and volatile organic chemicals	Removal of gases, oxidation of inorganics, particle removal by flotation
Lime	makes the water less acidic and helps to remove harmful substances like phosphorus and metals [8]	Chemical reaction of inorganics
Chlorine-Dosage	controlled addition of chlorine in its various forms such as gas, liquid or chlorinated compounds to kill bacteria, viruses and other organisms	Inactivation of microorganisms and oxidation of organic substances
Aquatextiles	high-performing aquatextiles designed specifically for stormwater management applications for roads and parking areas [9]	Particle removal
Flocculation	adding a flocculant to the water, which causes the suspended solids to clump together and form flocs to remove suspended solids from water	Particle removal
Adsorption: Activated Carbon	extremely porous solid carbon, usually in powdered block or granular form removing organic compounds and/or extracting free chlorine from water	Adsorption of organic substances
STOPPOL® plant	Innovative concept in which the separation of pollutants takes place through the inclined discs in a counterflow process [10]	Adsorption of organics
Disinfection: UV	Disinfection method using ultraviolet (UV) light, particularly UV-C (180–280 nm), to kill or inactivate microorganisms	Inactivation of microorganisms
Nanobubbles	sub-micrometer gas-containing cavity, or bubble, in aqueous solutions with unique properties caused by high internal pressure, small size and surface charge that can interact with and affect physical, chemical, and biological processes	Inactivation of microorganisms and biofilms and particle removal
Membrane filtration: Ultrafiltration	forces such as pressure or concentration gradients lead to a separation of macromolecules (10^3–10^6 Da) through a semipermeable membrane	Removal of microorganisms
Ozonation	Oxidation and/or disinfection process using ozone gas	Oxidation of organic substances and inactivation of microorganisms
H_2O_2-Dosage	Oxidation and/or disinfection process using hydrogen peroxide	Oxidation of organic substances and inactivation of microorganisms
Membrane filtration: Nanofiltration	uses nanometer sized pores through which particles smaller than about 1–10 nanometers pass through the semipermeable membrane	Removal of dissolved substance
Membrane filtration: Reverse osmosis	pressure operated semipermeable membrane process in which the smallest molecules as well as polyvalent and monovalent ions are almost completely separated from a solution	Removal of dissolved substances

Table 11 Ranking of installation categories for the technical treatment solutions.

Technical treatment	Installation costs	Maintanance costs	Personnel requirements	Robustness	Material requirements	Applicability	Water throughput	Space needed	Sum
Rapid sand filters	3	3	3	3	3	3	3	2	23
Slow sand filters	3	3	3	3	3	3	3	2	23
Aeration basin	3	3	3	3	3	3	3	2	23
Lime	2	3	3	3	3	3	3	2	22
Chlorine-Dosage	2	3	2	3	3	2	3	3	21
Aquatextiles	3	2	2	2	3	3	3	3	21
Flocculation	2	2	2	2	2	2	3	3	18
Adsorption: Activated Carbon	2	2	2	2	2	2	3	3	18
STOPPOL® plant	2	2	2	2	2	2	2	2	16
Disinfection: UV	2	2	2	2	1	2	2	3	16
Nanobubbles	2	1	2	2	2	2	3	2	16
Membrane filtration: UF	2	2	1	1	1	1	2	3	13
Ozonation	2	1	1	1	1	1	3	3	13
H_2O_2 Dosage	2	1	1	1	1	1	2	3	12
Membrane filtration: NF	1	1	1	1	1	1	1	3	10
Membrane filtration: RO	1	1	1	1	1	1	1	3	10

Compared to the natural, semi-natural and semi-technical solutions, it is immediately noticeable that there is no green tiles, because technical solutions require mostly higher efforts in all categories. Among the technical solutions, sand filters and aeration basins can be affordable opportunities, if the water use requires a better quality regarding removal of organic load. However, even if the construction and technical requirements of a sand filter can be much lower compared to highly technical methods like membrane filtration or others, sand filters can clog regularly and thus need to be refurbished or maintained frequently. They can easily lose their performance as biofilms are growing on the sandy materials and thereby reduce the flowrate through the filter. The installation costs of all methods, where dosages of chemicals are somehow required (e.g. chlorine, flocculation, ozonation or hydrogenperoxide), were categorized as quite high (2). They can be applied to remove inorganic components, organic components or microorganisms from water. So, the effort of installation and operation is comparable, but can be adjusted to the specific water quality required for a special use. Membrane filtration techniques, as well as H_2O_2 dosage and ozonation have the lowest numbers in the ranking, as they require lots of planning, energy, space and are prone to technical issues. However, these treatment techniques mostly only have to be applied, if drinking water quality is required. Since there are so many other possible solutions to use untreated or just slightly treated roadwater, these treatment solutions must only be considered in very specific cases.

4.4 Early warning and communication

Current early warning systems are established to facilitate peoples' safety and stabilize infrastructures in case of extreme weather events. Systems exist in Germany, France and the Netherlands, e.g. for high river or sea water levels. There are no efforts undertaken yet to use these systems also sufficiently to trigger or control operations related to water management and reuse. However, there are some ideas, how water infrastructure and early warning systems could be interconnected.

1) In case of heavy rain announcements, buffer systems could be emptied as a direct consequence to enlarge the buffer capacity for the increased amount of precipitation. Buffers for e.g. firefighting water storage or other purposes, could slowly release their water to rivers/ the sea days before the heavy rain and be refilled during the rain event again. In Germany, a regulation was recently put into force, that operators of dams and drinking water reservoirs need to adjust the filling level of the reservoirs according to current announcement of heavy rainfalls to offer more buffering capacity and thus, reduce the risk of floodings. Also dosing systems next to federal highways in Germany are regulated automatically to avoid water bodies that are already full to receive more water and thus, prevent floodings.
2) In case of drought warnings, the water management could be influenced in terms of starting early with collecting water and store it in evaporation protected buffer systems. Especially if buffer systems are constructed e.g. below roads, they could be used for road cooling and efficient water storage for extremely dry and hot periods.
3) Creating data rooms that list availabilities and qualities of water resources could in general help with optimized management of targeted water distribution. If a state could be reached in near future, where we make regular use of roadwater for a variety of purposes and in parallel make detailed documentations of the roadwater quality, reuse category, storage or distribution method in national or even transnational databases, AI-based technologies could help with fair distribution and regulation of availability in cases of extreme weather.

These are just some ideas on how early warning systems could be connected to roadwater management. Such considerations must be included in future water management concepts in order to create a good balance between water security, water regulation and water availability.

4.5 Water quantity and distribution limitations

Even if there are opportunities to treat roadwater, also the infrastructure must be given 1) to collect and transport the roadwater to the treatment area and/ or 2) to transport the treated/cleaned water to the place where it is needed in case there is no local use opportunity, which always should be checked initially. Therefore, rivers and existing canals could be used as non-cost transportation infrastructures if a transport of uncleaned water is required and it can be guaranteed, that the roadwater will not decrease the quality of the river, which can be avoided by slow release and thus strong dilution effects. It is also possible to install transportation pipes for already cleaned water. In that case, it must be emphasized, that such pipe systems can then only be used for the transportation of treated water and no water of lower qualities must be fed in here. Examples of "treated water distribution" are long-distance drinking water supplies (in German "Fernwasserversorgungen"), which allows for instance the transportation of treated/cleaned drinking water from Lake Constance over several regions in South-west Germany via tunnel pumping. Also, pipes for directed transportation of river water (water of lower quality compared to drinking water) to open-cast mining sites have been recently constructed in Germany. Such systems could be used more easily to also spike and transport roadwater, as no specific water quality is required at the point of use. All in all, transportation systems for a variety of water qualities do already exist or can be constructed, if the benefit is high enough, which is often the case. Therefore, existing infrastructures should be checked for their suitability for roadwater transportation.

The consortium "Roads for Water" (www.roadsforwater.org) offers a collection of worldwide case studies, especially from countries that suffer from extreme droughts, where roads have been made into instruments for water management. To catch up ideas, strategies and methods, that were successfully applied in countries such as Ethiopia, Kenya, Uganda, Tanzania, Malawi, Zambia, Mozambique, Bangladesh, Nepal, Tajikistan, Pakistan and Bolivia, will also help NWE countries to implement new solutions for efficient roadwater collection, storage, distribution and reuse.

5 Conclusion

This document delivers a comprehensive overview about the existing roadwater cleaning strategies in the RRR partner countries and gives insights to further cleaning solutions on more technical levels. Several ideas for roadwater uses are presented and ranked according to their possible realization or implementation, looking at criteria like costs, robustness and water quality. The existing roadwater quality and the required water quality for a specific use case will determine how big the effort must be to clean the water. Categorized according to the technical level, many opportunities to treat roadwater are given within this deliverable. A ranking from 1 to 5 or red to green indicates e.g. how expensive/cheap, vulnerable/robust or applicable a treatment solution could be. The proposed solutions were collected by a consortium of experts in the specific fields of federal highway management and general water treatment. Thus, they are a good starting point for detailed considerations on roadwater reuse opportunities. It can help authorities, that struggle with too high amounts of water after heavy rains, too low amounts for agricultural, cultural, municipal or industrial use in dry periods or water users looking for cheaper, more sustainable or generally available water resources for a specific application. Decision makers hopefully will be motivated to take these and similar solutions into account when planning future infrastructures with more circulatory water systems. It gives some examples for uses or treatment methods considered or already implemented in the NWE countries. Hopefully, it will allow to convince stakeholders, that roads could be water suppliers instead of only water polluters.

6 References

[1] **European Union (2020)**: DIRECTIVE (EU) 2020/2184 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: on the quality of water intended for human consumption (recast). L 435/1.

[2] **European Union (2020)**: REGULATION (EU) 2020/741 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: on minimum requirements for water reuse. 5.6.2020.

[3] **European Union (2006)**: DIRECTIVE 2006/7/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: concerning the management of bathing water quality and repealing Directive 76/160/EEC. L 64/37.

[4] **Pompigna, A., Mauro, R. (2022)**: Smart roads: A state of the art of highways innovations in the Smart Age, *Engineering Science and Technology, an International Journal* 25 (2), p. 100986. DOI: 10.1016/j.jestch.2021.04.005.

[5] **European Union (2000)**: DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: establishing a framework for Community action in the field of water policy. L 327/5.

[6] **Hashem, S., Cardiño, C. (2020)**: Innovative Pavement Materials and Design: Smart Roadways and Smart Road Maintenance for the Future, p. 75–83. DOI: 10.29117/cic.2020.0011.

[7] **Kayhanian, M., Weiss, P.T., Gulliver, J.S., Khazanovich, L. (2015)**: The Application of Permeable Pavement with Emphasis on Successful Design, Water Quality Benefits, and Identification of Knowledge and Data Gaps, *Open Access Publications from the University of California*.

[8] **Nordkalk (2024)**: Water Treatment with Lime Products, available from https://www.nordkalk.com/water-treatment-with-lime-products/. Accessed on 2024/12/05.

[9] **OSMORIA (2024)**: The future of stormwater management: Pioneering Aquatextiles, available from https://www.aquatextilesosmoria.com/. Accessed on 2024/12/05.

[10] **Saint Dizier Environment**: STOPPOL®: Anlagen aus GFK zur dezentralen Niederschlagswasserbehandlung für Strassen & Industrie & Siedlungsgebiete, available from https://www.saintdizierenvironnement.eu/produit/1162/dezentraler-abscheider-stoppolr-?lang=fr. Accessed on 2024/12/05.