TRAFIKVERKET

RAPPORT

Reducing Highway Runoff Pollution (REHIRUP)

Sustainable design and maintenance of stormwater treatment facilities

NordFoU

Trafikverket
Postadress: Adress, Post nr Ort
E-post: trafikverket@trafikverket.se
Telefon: 0771-921 921

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Författare: Jonas Andersson, Josef Mácsik, Dimitry van der Nat, Anna Norström, Marie Albinsson, Sofia Åkerman, Preetam C. Hernefeldt, Robert Jönsson
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1 Introduction

Management practices for handling highway runoff differ between the various European national road administrations. These differences manifest themselves in different approaches related to planning, construction and operation of runoff treatment facilities. For example, Sweden, Norway and Germany, use different standard guidelines when managing stormwater. Proprietors, owners, consultants and building contractors involved in design and construction of treatment facilities are accountable for meeting the requirements set by the national road administrations or by the national environmental authorities, (Ranneklev et al., 2016).

With the aim of compiling current practice and knowledge of stormwater best management practices (BMPs) the Swedish Transport Administration (STA), the Norwegian Public Roads Administration (NPRA) and the Danish Road Directorate (DRD) initiated the collaborative project "Reducing Highway Runoff Pollution" (REHIRUP). This project aims to provide a basis for design, operation and management of environmentally safe and cost-effective stormwater BMPs. Thereby, REHIRUP endeavours to contribute to the overall goal of improved pollutant retention efficiencies, enhanced degradation of organic pollutants, optimised multiple use of the land utilised for runoff management, and an overall better utilization of resources.

One of the project objectives is to provide recommendations for maintenance of future BMPs such as settling ponds, subterranean stormwater storage facilities and filters, and thereby improve road runoff management in an environmentally and economically sustainable way.

This report summarizes outcomes of two work packages (WPs) of the REHIRUP project, namely Maintenance (WP2) and Sustainable design (WP4). The conceptual framework of the two work packages is described in Figure 1.1.

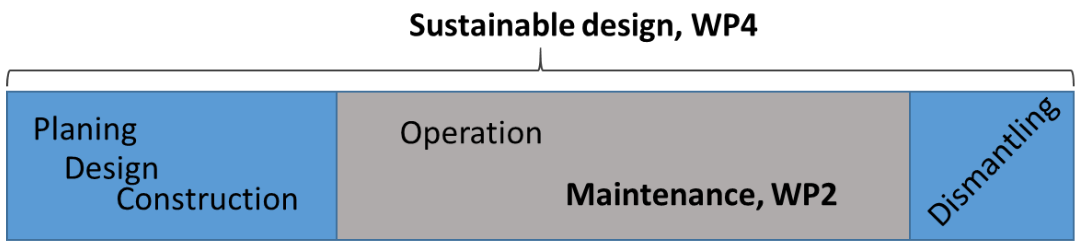


Figure 1.1. Conceptual framework linking WP2 and WP4, where WP2 deals with the management and maintenance of stormwater sediment and WP4 with the design of sustainable stormwater facilities.

1.1 Aims and goals

For this report, the aim of the section Maintenance (WP2) is to identify current handling practices of stormwater sediment, and for sustainable design (WP4) the aim is to identify sustainable alternatives for the future design of stormwater facilities based on experience from Sweden, Norway, Germany, Austria and Switzerland. The common goal for both work packages is to formulate practical recommendations for sustainable sediment management and the design of future BMPs.

1.2 Method

Each work package is divided into three distinct parts:

A) "State of the art" - comprising a literature review and interview survey.
B) "Analyses and evaluation" - comparison of different design and maintenance methods.
C) "Recommendations" - based on the findings from parts A and B

Methods and approach for each of these parts are described below. This report covers the part A, B and in parts C.

2 Background

2.1 A) State of the art and B) Analyses and evaluation

This section of the report aims to review current management practices for stormwater as well as subsequent sediment handling across a selection of European countries with comparable climates, i.e. Norway, Sweden, Germany Austria and Switzerland. Practices used in the different countries were elicited through a review of the relevant literature and interviews with local experts.

The literature review focused on:

- General contamination levels in road runoff.
- Current and alternative handling practices and their respective pollutant removal efficiencies, sediment properties and pollution distributions.
- Sediment handling practices, e.g. dredging.

The interviews focused on:

- National legislation and requirements.
- Planning, design, construction and operation of treatment facilities.
- Performance and functionality of facilities.
- Operational and maintenance costs.

The goal of the literature review was to provide a basis for analysing effectiveness and sustainability of different handling alternatives. The surveys focused on national conditions and their effects on different sediment handling alternatives and maintenance costs. Experiences with different removal and treatment techniques and the costs associated with the main alternatives were described and critical moments in the treatment chain were defined. The objectives were to describe design and efficiency of the national stormwater facilities, measured as length of road/cost, maintenance/cost, volume sediment/road length, cost etcetera.

Sediment treatment and management is affected by national BMPs, the type of sediment present, combined with the sediment removal technique and dewatering method used. The latter factors also affect deposition and treatment costs of removed sediments. Of key interest are observations of how sediment removal techniques may affect runoff and seepage of harmful substances. However, the most important cost drivers are the source of runoff, the design of the treatment facility, as this can produce different sediment quantities and qualities based on content of water, fines, total organic carbon (TOC) and contamination.

2.2 Governing laws and legislation

Each country included in the review has its own legislation for protecting the environment and receiving waterbodies. Yet, at the same time, all EU countries have to comply with the EU Water Framework Directive (WFD) and its daughter directives. Several non-EU-member states, such as Norway and Switzerland have adopted the WFD or legislation consistent with it (Meland, 2016). The WFD stipulates that all waterbodies should achieve a "good status" and therefore neither quality, nor quantity or ecology may be reduced for surface-, coastal- and ground water. Several of the priority substances, presenting a significant risk to or via the aquatic environment, typically occur in urban runoff. One of the goals of the WFD is to reduce levels of these priority substances to levels that pose no negative impact on the aquatic environment. The responsibility for managing road runoff according to the WFD guidelines in Sweden lies with the National Road Administrations (Trafikverket, 2013).

2.3 Management of stormwater

The fact that urban stormwater generally requires treatment in terms of quantity and quality is well recognised. It is widely acknowledged that reduced soil permeability due to urban development and paving activities combined with the installation of conventional fast-draining stormwater grids reduce the infiltration of stormwater into the soil and promote rapid runoff. Thereby, the resulting high stormwater flows and associated physicochemical pollutants negatively affect the water quality in the receiving surface waters. Management practices for road runoff should therefore target pollutant retention as well as peak flow reduction and flood risk management.

In addition to the WFD and national legislation, there is a wide array of national and regional guidelines, recommendations and requirements that determine the methods available for runoff treatment. Our literature review revealed that only limited information is available on the development of guidelines for runoff treatment. In Sweden and Norway policy documents and guidelines are qualitative and focus predominantly on water quality, retention capacity, aesthetics and ecology. In contrast, German Austria and Switzerland policy is quantitative and includes focus on particle transport with total suspended solid (TSS) particle load being recognised as the major pathway for traffic-borne pollution. Policy documents and guidelines are described per country below.

2.4 Pollutants and sources

Pollutants present in stormwater, originate primarily from car traffic and are linked to exhaust, corrosion, tire and brake pad abrasion, road wear, lubricants and catalytic converters (Trafikverket, 2011). Stormwater typically contains a complex cocktail of suspended solids (TSS), heavy metals, hydrocarbons, plastic and rubber particles, nutrients and chlorides from road salt. Synergistic effects from pollutant cocktails pose an additional substantial environmental risk to receiving environments (Trenouth & Gharabaghi, 2015). Examples of pollutants occurring in stormwater as well as their sources and environmental impact are summarised in Table 2.1.

The composition and concentration levels of pollution in road runoff are affected by a number of factors, such as climate, traffic intensity and the ratio between light and heavy traffic. During winter, suspended solid loads strongly increase in Sweden and Norway when studded tires are used which increase road wear (Meland, 2016; Trafikverket 2011). Increased loads of suspended solids lead to increase pollutant transport to receiving waterbodies as well as having a negative impact on air quality.

The composition of particles and dissolved pollutant levels in road runoff strongly depends on local parameters (Trafikverket, 2011). Physical and chemical parameter which control the transport and fate of metal pollutants include solubility and salinity. For instance, metals like copper, nickel, zinc and cadmium can occur at a higher fraction in the dissolved phase, while chromium and lead are mostly particle-bound (Huber et al., 2016). Dissolved pollutants are often more mobile and bioavailable and will not be removed using only mechanical methods. Salinity of road runoff is increased when applying salt on roads for de-icing. Salt (chlorine in particular) can mobilize particle-bound heavy metal ions through competitive ion-exchange (Lacy, 2009) and thus increase the portion of dissolved heavy metals (Amundsen et al., 2010).

Table 2.1. Examples of sources and effects of different pollutants found in road runoff, based on Fredin 2012. Primary references: Larm and Pirard 2010, Malmö Stad 2008, Naturvårdssverket 2008, Stockholm Vatten 2001, Trafikverket 2011, Dupuis 2002.

Category	Source	Pollutant	Environmental effect
Particles	Tire & road wear (micro plastics), brake pads, corrosion, road side erosion	Suspended solids	Act as transport for other pollutants, disturbance of habitats due to siltation
Metals	Road wear, brake pads, corrosion, catalytic converters, fuel, paint, road equipment	Lead * Mercury * Nickel * Cadmium * Chromium Zinc Copper	Negative health impact on humans and animals if consumed at certain concentrations. Toxic to aquatic life. Potential negative effect on local flora.
Organic substances	Tire wear, road wear, combustion, oils	PAHs * (€)	Toxic to aquatic life, carcinogenic and toxic to humans at certain concentrations.
De-icing agents	Road salts	Sodium Calcium Chloride	Increased salinity, mobilization of particle-bound heavy metals
Nutrients	Atmospheric deposition, combustion fumes, animal faeces, oils, soil particles, plant residues, animal faeces	Phosphorous Nitrogen	Eutrophication

* Priority substances under the Water Framework Directive
(€) Naphthalene etc.

Reference values of typical pollutant concentrations in runoff from roads are presented in Table 2.2. The volume of road runoff depends on precipitation and infiltration capacity of the road shoulder and embankment. Annual Daily Traffic (ADT) is used in several European countries to model pollution levels and the need for treating road runoff. However, the practice of modelling pollutant load by using ADT is debated (Meland, 2016). For example, cars traveling on road networks containing a high number of traffic signals generally decelerate (resulting in increased brake pad use) and accelerate more frequently than in areas where few traffic signals are used. Frequent deceleration can increase pollutant levels to such an extent that low ADT roads (with many traffic signals) have higher levels of pollutant runoff than high ADT roads (without traffic signals) (Huber et al., 2016).

Table 2.2. Standard values for concentrations of pollutants in stormwater and percentages of dissolved fraction in stormwater from mixed urban areas.

Parameter	Unit	15 000 - 30 000 ADT[1]	>30 000 ADT[1]	Dissolved fraction in stormwater[2]
Phosphorous	[mg/l]	0.20	0.25	5-80 %
Nitrogen	[mg/l]	1.5	2.0	65-100 %
Lead	[µg/l]	25	30	1-28 %
Cupper	[µg/l]	45	60	20-71 %
Zinc	[µg/l]	150	250	14-95 %
Cadmium	[µg/l]	0.5	0.5	18-95 %
PAH	[µg/l]	1.0	1.5	10-15 %
Suspended solids	[mg/l]	100	1000	-

[1] Trafikverket (2011), [2] Larm & Pirard (2010)

Around 15-30 % of road traffic emissions end up in runoff, while the remaining is carried away by wind, vehicle splashes and wind-blown spray in wet weather or by maintenance activities such as road sweeping (Trafikverket, 2011; Billberger, 2016). If roads are drained via conventional stormwater grids without infiltration, the entire pollutant load is expected to follow with the runoff, while much of the pollutants are retained on the road-side when runoff is infiltrated there. The literature indicates that the proportion of pollutant transport that occurs with the runoff can be as little as <20%, but also close to 100% (Trafikverket, 2011).

The loads reaching surrounding waterbodies varies greatly and depends on aspects such as wind, traffic intensity, road materials and road angle as well as road embankment design and filtration capacity, design of side ditches, soil type the runoff passes on its way, and distance to receiving water.

2.5 Principles of stormwater treatment

Several principles for designing road runoff treatment facilities exist with varying functionalities that can either promote a single treatment technology or focus on several treatment processes for a more complete function. The design aims can be flow limitation, removal of coarser and/or finer sediments, and removal of dissolved pollutants or prevention of negative impacts on receiving waters from accidental emissions (Figure 2.1).

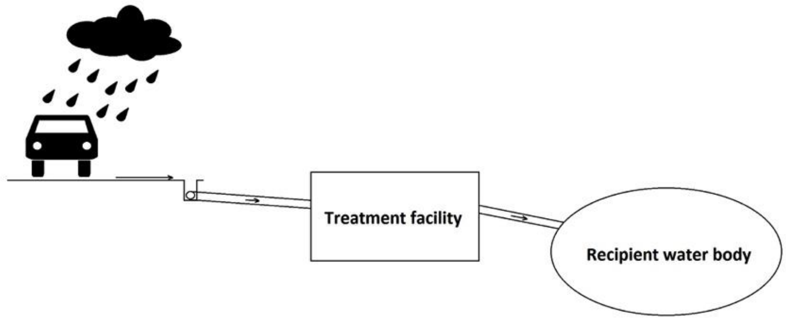


Figure 2.1. *A schematic sketch showing the course of the runoff from a source to a receiving waterbody, passing a treatment facility. Illustration: Robert Jönsson WRS.*

Removal of pollutants can be achieved by, e.g. sedimentation (particle bound contaminants), filtration (dissolved/colloidal contaminant), adsorption (dissolved contaminant), and microbial processes (degradation, reduction/oxidation). When managing road runoff, Huber et al., (2016) recommend treatment of the entire runoff volume rather than the initial volume only of a storm event. Accurate calculation of the design flow is therefore of key importance for all types of treatment facilities (Blecken, 2016). Different methods for classifying the suspended solid fraction in road runoff are in use, such as the classification system following Roesner et al. (2007), where:

- particle size < 2 µm including colloids is classified as dissolved;
- particle size 2 – 75 µm is classified as fines containing clay and silt;
- particle size 75 µm – 5 mm is coarse containing silt and sand;
- particle size > 5 mm is coarse containing sand and gravel.

Table 2.3 summarizes which particle fractions that are typically well retained in different treatment facilities. Sediment traps, retention basins, swales and ponds are effective in reducing sand, gravel and fine particulates. Infiltration facilities, designed swales and membrane filters are suitable for reducing colloidal particles and can adsorb dissolved contaminants.

Table 2.3. Suitability of treatment methods according to particle size ranges (Blecken, 2016).

Facility\Particle size	>5 mm	5 mm - 125 µm	125 µm - 10 µm	10 µm - 0.45 µm	<0.45 µm (dissolved pollutants)
Sediment trap					
Underground retention basin					
Stormwater pond					
Swale					
Infiltration facility					
Rain garden, biocell					
Membrane filter					

2.6 Treatment technology for stormwater

This chapter contains a description of the most common systems for treatment of stormwater, namely 1) infiltration into road shoulders, road embankments and grassed side ditches, 2) stormwater ponds and wetlands, 3) sedimentation basins and centralised infiltration facilities and 4) combined sedimentation and infiltration facilities. There are also more technically advanced systems in use for centralised treatment, however, for the purpose of this report we focus on the systems most commonly found in the selected European countries and those considered by practitioners as robust.

2.6.1 Infiltration in road shoulders, road embankments and grassed side ditches (swales)

The most widespread method for treatment of rural road runoff is local infiltration into the road shoulder and embankment. In many cases it is combined with grassed side ditches (grassed swales). In Germany, Sweden Norway and Switzerland treatment using infiltration into the road shoulders and embankment is often preferred and considered sufficient outside sensitive areas. The Swiss Federal Office for the Environment recommends infiltration in road shoulders when possible (Trocme et a., 2013). Simulation of infiltration and in situ monitoring of runoff show that most, if not all, of the polluted water infiltrates the embankment, and that there is little and slow drainage at the bottom of the embankment (Boivin et al. 2008). The same study suggested that most of the heavy metals (Pb, Zn, Cu, Ni and Cr) were filtered or adsorbed in the embankment.

As stormwater infiltrates into the road shoulder and embankment, further percolation usually occurs into the underlying groundwater. In circumstances where infiltration is efficient, it is expected that most pollutants are caught in the soil profile (Trafikverket, 2011). However, if infiltration capacity is low and surface flow predominates, the road embankment acts as a vegetative filter strip (VFS) and a slightly lower separation of pollutants can be expected. Examples of typical treatment result are presented in table 2.4.

Excessive road runoff which has passed over a vegetated embankment, can be further treated through infiltration into grass-covered side ditches (grassed swales). The vegetation also decreases the runoff velocity. Course particles are reduced in the runoff by filtration through the vegetation, sedimentation and in some cases infiltration before the runoff is directed into the drains or percolates into the ground water. If the soil's infiltration capacity is sufficiently high to avoid stagnant water, the drain-inlet can be elevated to increase residence time and sedimentation.

A swale primarily separates sand and other coarser particles through sedimentation. Swedish studies report a removal efficiency of 20-25 % for total suspended solids and 20 % for metals (Bäckström, 2002). Higher efficiencies are reported in international studies (Blecken, 2016).

The Swedish Transport Administration (STA) concluded that grassed side ditches (swales) have good ability to remove metals as well as different petroleum products the latter can be further reduced through biodegradation (Trafikverket, 2011). However, the separation of pollutants is lower than that of infiltration facilities, Table 2.4. Swales alone should not be considered as complete stormwater treatment, but can be used as effective pre-treatment steps to be followed by ponds or other infiltration facilities (Blecken, 2016). They can also be used to transport excess water that is not infiltrated during heavy rains.

The removal efficiency of the swales is influenced by the design. For examples, a short ditch with a drain through a well or pipe at the bottom, primarily captures sand and contaminants bound to coarser particles. Longer ditches with outflow limitations have greater ability to separate both coarser and finer particles and hence a higher proportion of particulate contaminants. A long, grassed ditch on soil with good infiltration capacity can also contribute to limited separation of dissolved pollutants.

According to STA Trafikverket (2011) grassed side ditches, in combination with infiltration in road shoulders and road embankments are often the most cost-effective treatment alternative. In addition, there is usually potential to make treatment and flow management more effective through choice of design and materials.

Table 2.4. Estimated removal efficiency in various types of treatment systems. The values given in the table are based on scientific data, but due to the lack of relevant data in some cases, assumptions have been made of functionality in relation to other types of installations (Stockholm Vatten, 2017).

Treatment system	Tot-P	Tot-N	Tot-Cu	Tot-Zn	SS	Oil	PAH16
	[%]	[%]	[%]	[%]	[%]	[%]	[%]
Grassed side ditch (swale)	30	40	65	65	70	80	60
Pond	50	35	60	65	80	80	70
Wetland	50	35	60	65	85	90	70
Sedimentation basin	55	15	60	65	75	65	60
Centralised infiltration facilities (soil infiltration)	65	40	65	85	80	80	85
Combined sedimentation and infiltration facilities	≥65	≥40	≥65	≥85	≥80	≥80	≥85

2.6.2 Stormwater ponds and wetlands

If roadside infiltration is impossible or inappropriate, centralised treatment is required. Wet ponds are amongst the most common centralised treatment facilities for stormwater in Sweden and Norway. These are sometimes designed as wetlands. Open, nature-based stormwater treatment systems are, according to the Swedish STA Trafikverket (2011), usually more cost-effective than technical solutions, such as underground sedimentation basins or filters.

The removal process of particle-associated pollutants occurs mainly through sedimentation. By total mass, the main portion of suspended solids consists of larger particles (Table 2.3). For easier maintenance and better performance ponds are often equipped with a so-called forebay; an initial separate section of the pond dedicated to sedimentation of larger fractions. When designing a stormwater pond, attention should be paid to effective design of hydraulic structures like inlet, outlet and overflow structures (Blecken, 2016). Hydraulics can be improved by a subsurface berm or an island placed near the inlet. A submerged outlet will facilitate the trapping of oils and other volatile pollutants at the surface, while cleaner water will pass below. It also promotes the mixing of surface water and deeper water, which will promote aeration and also counteract stratification, Andersson et al. (2012). A common recommendation for the area needed for the pond is 1-2 % of the impervious catchment area. The hydraulic performance of the pond is of key importance for its sedimentation capacity. Several design criteria, such as for instance a high length-to-width ratio can improve the hydraulic efficiency of a facility. Many existing ponds are poorly maintained, illustrating the need for routinely scheduled maintenance for all facilities (Blecken, 2016).

The treatment efficiency of a pond or wetland is affected by many different factors, e.g. sedimentation performance. The removal ability of ponds for suspended material lies in a range of 65-90 %. The higher percentage applies to facilities where incoming concentrations of suspended solids are very high and to facilities that can also capture finer sediments (usually wetlands and ponds containing a vegetation zone). Wetlands and ponds with a vegetation zone usually have good ability to remove phosphorus (30-65 %) and metals (around 60 %). In large, shallow and vegetated areas, biological processes can contribute significantly to further reduction and retention of nitrogen and other dissolved pollutants. Wetland has relatively higher capacity to separate dissolved pollutants, compared to ponds. Typical treatment results are presented in table 2.4.

2.6.3 Sedimentation basins

When the spatial requirements for constructing a stormwater pond cannot be met on the surface, compact or underground sedimentation (retention) basins can provide an alternative. If correctly designed, they have a good ability to remove particle-bound pollutants by sedimentation. However, their biological treatment processes is negligible due to the absence of vegetation (Blecken, 2016). The basins are often cast in concrete, but can also be supplied as pre-constructed plastic chambers.

Treatment mainly occurs through sedimentation of suspended solids and particle-bound pollutants. The degree of treatment depends on the flow conditions in the basin. The removal efficiency can be 30-65 % for total metals and up to 50 % for total phosphorus. Particle-bound oil contaminants are also separated through sedimentation. If the outlet is submerged, oils and other volatile pollutants on the surface of the water will be trapped. Filters and addition of chemicals to promote precipitation can enhance the removal of particulate pollutants and also allow for the capture of dissolved pollutants. Typical treatment results are presented in table 2.4.

2.6.4 Centralised infiltration facilities and combined sedimentation and infiltration facilities

A centralised stormwater infiltration system allows accumulated runoff water to infiltrate through soil, to either the groundwater table (percolation), a stormwater pipe collection system or nearby surface water via a drainage system. Infiltration facilities are typically designed to infiltrate the entire volume of stormwater resulting from a design storm in the catchment area. Site-specific groundwater levels and soil infiltration capacity are important design parameters.

Infiltration facilities can capture a high proportion of particle-bound pollutants and remove dissolved pollutants through the infiltration of water into the soil. The ability to separate particulate pollutants is in the range 60-95 %. The total removal efficiency is determined by factors, such as, soil depth, infiltration capacity and affinity of the contaminants to the soil. Infiltration facilities can contribute to a high reduction of metal contaminants and plant nutrients (Table 2.4).

Soil filtration of stormwater is commonly applied in Germany and Austria along large highways. The infiltration is typically preceded by a sedimentation basin for coarse particles and an oil separation compartment to retain organic volatiles. The soil filter mainly removes fine particles and organic material. The fines and organic material that accumulate in the filter layer contribute to retention of dissolved organic and metal pollutants.

To avoid overflow, the facilities are often constructed with adequate retention capacity to deal with intense rain events and emergency spillways to bypass volumes exceeding capacity. Soil filters typically consist of a filter layer of a mixture of medium sand (0,2 – 0,6 mm), basalt, pumice and carbonate. Complete drainage to dry state should occur within 24-48 hours to prevent clogging of the soil filter.

The most effective treatment can be reached by combining complementing technologies, as in the German and Austrian example (Marsalek et al., 2006). Most pollutants, inorganic as well as organic, are often present both in solution as well as in association with particles. Facilities with mainly mechanical (sedimentation based) pollutant removal might need a complementary treatment step (e.g. infiltration) to reduce dissolved pollutants (< 2µm), colloids and fine particulates (Huber et al., 2016). By combining different types of treatment systems life-time of the facility is also often increased, while the need for maintenance is decreased. Problems with fine particles clogging the pores of infiltration facilities can be mitigated by pre-treatment, using e.g. a sedimentation pond a swale or a filter strip (Blecken, 2016).

2.6.5 Technically advanced systems

In areas with special conditions, such as a shortage of space, high flows, sensitive ground -or surface water, it may be necessary to implement more technically advanced systems for stormwater treatment. In most cases the facilities are installed underground and occupy only a small amount of surface space. Generally, these systems have the same function as the standard system, but are much smaller, and commercial products are usually used for filter material etc. The technically advanced systems are often designed to treat only the first flush of a storm event (the first 15 minutes of rainfall, one-tear return period) (CEDR, 2016). There are several technically advanced systems, for example:

- Sedimentation basins with chemical treatment (addition of flocculation chemicals).
- Sedimentation basins with pH-adjustment.
- Filter facilities. Peat, pine bark chips, iron oxide sand, activated carbon, blast furnace slag, lime and zeolites are examples of common filter materials.
- Technical filter plants, a collective term for a number of small stormwater treatment plants. Treatment is done by filtration, using mechanical, chemical and/or biological

techniques. The plants may also contain steps to remove litter, suspended materials and oil.

The filter material used and the treatment steps included determine the treatment efficiency.

2.6.6 Other systems

Besides the above-mentioned systems, there are other systems that are becoming more common along smaller roads:

- *Permeable pavements*
  Roads and parking places can be constructed using permeable pavement material, such as porous asphalt and concrete pavers. To avoid overflow, these facilities are sometimes constructed with a temporary storage capacity for water which is not infiltrated immediately. Permeable pavements allow water to infiltrate through its surface voids into an underlying material for storage and filtration. Course materials allow faster infiltration at the cost of decreased pollutant reduction while the opposite effect applies for finer materials. Regular maintenance is necessary to maintain infiltration capacity and treatment effect. Finer sediments are known to clog the filter surface and it is recommended that the top layer is removed as soon as reduced infiltration rates are observed. Permeable pavements need regular cleaning by e.g. pressure washing and vacuum sweeping in order to maintain permeability. The designed infiltration capacity of permeable pavements should be sufficient to avoid accumulation of stormwater on the surface (Blecken, 2016). Sufficient infiltration capacity is even more important when facilities receive stormwater from adjacent surfaces.
- *Filter drain*
  A filter drain is usually built by filling a ditch with single-sized crushed stone. A drainage pipe is normally placed at the bottom of the ditch, which allows infiltration and drainage of stormwater, even at relatively high flows. A filter drain mainly removes suspended solids and particle-bound pollutants.
- *Infiltration trench*
  An infiltration trench is designed as a grassed side ditch or swale, on top of a layer of sand- or gravel-layer that promotes infiltration. The trench is often drained through a drainage pipe at the bottom of the gravel layer. There is no need for a drainage pipe if the underlying soil has good permeability.
- *Raingarden*
  A raingarden is a planted depression that can retain and treat stormwater runoff from impervious areas. Treatment occurs when the stormwater is filtered in the plant. Plant growth contributes both to purification and

maintaining infiltration capacity. Raingardens are often integrated in curb extensions.

- *Storm drain filters*
  Storm drain filters are treatment inserts that can be installed directly in existing storm drains. Treatment efficiency is affected by flow rate and the ability to treat different kinds of pollutants depends on the type of filter material. Most models are provided with a bypass to keep the flow through the filter at a reasonable level even during heavy rains.
- *Oil interceptor*
  Oil interceptors are designed to treat water with high concentrations of oil pollutants. The treatment effect is poor when the oil content is low (as it normally is in road runoff) and oil interceptors have limited ability to remove other pollutants. Oil interceptors are therefore used to complement other stormwater treatment facilities when there is a need for protection against temporary and larger oil spill.

2.7 Stormwater sediments

Road runoff contains various types of pollutants, with suspended solids being the largest fraction. The main sources of suspended solids in road runoff are pavement abrasion, vehicle abrasion, tire wear and surrounding land use. Pavement abrasion accounts for approximately 40-50 % of the sediment load followed by tire wear, which is about 20-30 % (Karamalegos et.al, 2005; Sansalone & Triboullard, 1999). However, the origin and amount of suspended solids in road runoff is site specific. For example, surrounding land use and activities such as construction work can contribute to high loads of suspended solids in road runoff. Similarly, high daily traffic intensity will lead to more suspended solids in road runoff (Ellis & Revitt, 1982). A study done by Winkler (2005) indicated that average sediment concentrations in road runoff (ADT > 10 000 vehicles/day) generate about 200 mg/l of total suspended solids (TSS).

Pollution (e.g. total suspended solids, heavy metals and of organic pollutants) from roads runoff can cause harm to the surrounding environment and poses a threat to the aquatic life, especially if allowed to accumulate and reach toxic concentrations. Pollution reduction is an important challenge for National Road Administrations in Europe (CEDR, 2016). When there is a risk, road runoff should be treated to eliminate damage of the receiving surface and ground waters. Stormwater facilities are therefore designed to store stormwater, immobilize suspended solids and contaminants in order to protect the downstream waters against pollution. However, this strategy leads to an accumulation of solids and pollutants in grit separators, ponds, wetlands, infiltration basins, bio-filters etc. In Sweden and Norway, one common method has been to collect the road runoff in ponds where sediment can accumulate, Figure 2.2a. The more efficient a pond is in accumulating fine particles and colloids the more contaminated it gets. With time, sedimentation leads to decreased water depth and increased water velocity and, consequently, decreased immobilisation of contaminants. To improve the efficiency of ponds or magazines, sediment must be removed, also, this can result in mobilization of fine particles and contaminants, if not handled correctly.

Pond sediment can increase concentrations of P from 36–150 times, Pb 5–80 times, Ni 400–700 times, Cu 76–10,000 times, and Zn 27–170 times compared with reference lake sediments (Istenic et al., 2012).

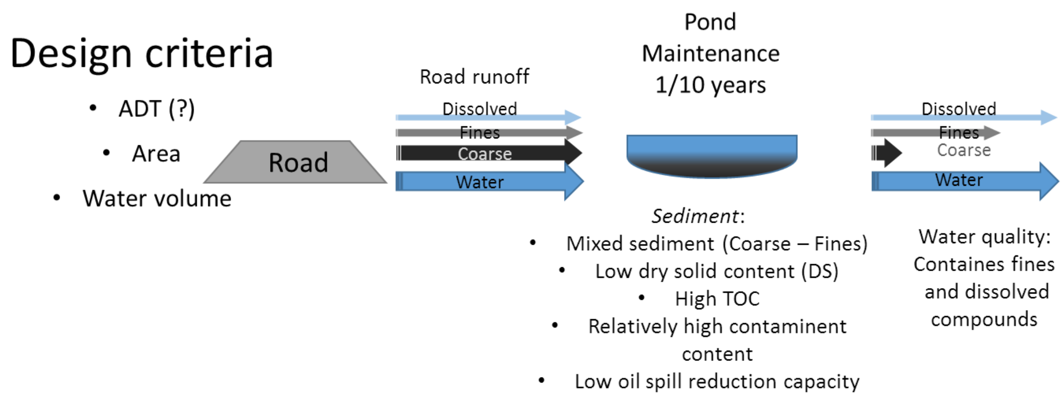


Figure 2.2. Ponds as centralised treatment facility are common in Sweden and Norway for treating road runoff.

However, ponds do not efficiently remove all pollutants. For example, wet detention ponds can efficiently remove metals such as Zn, Cu and Ni from stormwater, but dissolved and colloid-bound pollutants are generally poorly removed. A common removal method in Germany, and Austria is to combine sedimentation with infiltration in detention ponds, in order to improve the quality of the discharged water, Figure 2.3.

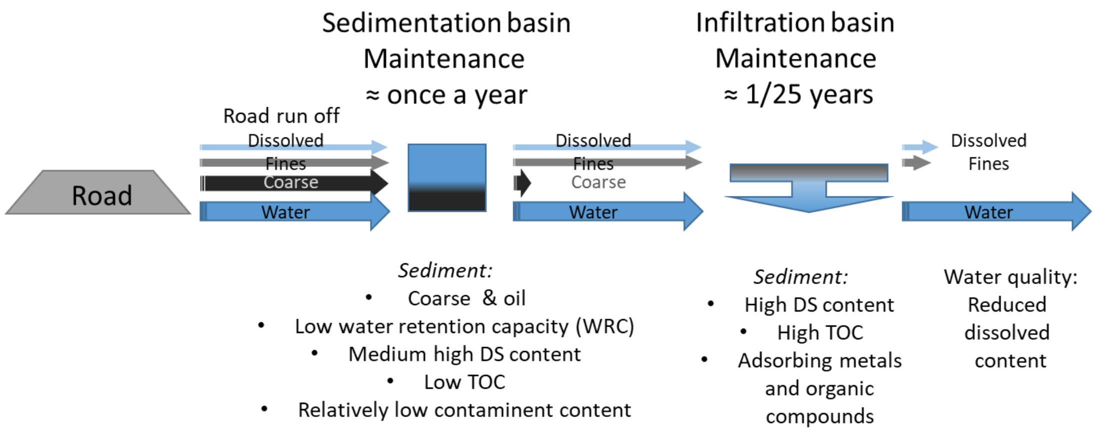


Figure 2.3. Combined sedimentation and infiltration basins are common in Germany and Austria for treating road runoff.

In a study by Istenic et al., (2012) three wet detention ponds were amended with sand filters, sorption filters and addition of precipitation chemicals to enhance the removal of dissolved pollutants and pollutants associated with fine particles and colloids. The sand filters at the outlets efficiently reduced the concentrations of most of the pollutants. The sorption filters contributed to further decrease the concentration of P2O4 from 0.04 ± 0.05 to 0.01 ± 0.01

mg/L and were also efficient in removing heavy metals. The translocation of heavy metals from roots to the aboveground tissues of plants was low. Therefore, the potential transfer of heavy metals from the metal-enriched sediment to the surrounding ecosystem via plant uptake and translocation was negligible.

The sorption filters that were established as an additional polishing technology at the pond at Odense showed good performance in removal of P and further removal of Zn and Cu, which were still in relatively high concentrations while entering the sorption filter. The long-term capacity of the filter is, however, not known.

Salt had a negative impact on outflow concentrations, causing lower removal efficiency for (especially dissolved) metals. This impact was most pronounced for Cu and Pb. Bio-filters showed the ability to treat stormwater efficiently under the simulated winter conditions, outflow concentrations for total metals as a minimum met the class 4 (high concentration/growing risk of biological effects) threshold value defined in the Swedish freshwater quality guidelines, while inflow concentrations clearly exceeded the threshold value for class 5 (very high concentration/effect on the survival of aquatic organisms even under short-term exposure). The relatively coarse filter material (which is used to facilitate infiltration during winter) did not seem to exacerbate biofilter performance (Søber et al., 2014).

Various combinations of sand, compost and other materials were observed to have excellent heavy metal removal (75–96% of Zn and 90–93% of Cu), with minimal DOC leaching (0.0013–2.43 mg/g). The sorption efficiency of the different Enviro-media mixes showed that a combination of traditional (sand) and alternative materials can be used as an effective medium for the treatment of dissolved metal contaminants commonly found in stormwater. The application of using recycled organic materials and other waste materials (such as recycled glass) also provides added value to the products life cycle. Compost (from garden waste) was found to have the best physicochemical properties for sorption of metal ions (Cu, Zn and Pb) compared with sand, packing wood, ash, zeolite and Enviro-media (Seelsaen et al., 2006). The compost sorption of these metal ions conformed to the linear form of the Langmuir adsorption equation with the Langmuir constants (qm) for Zn (II) being 11.2 mg/g at pH 5. However, compost was also found to leach a high concentration of dissolved organic carbon (DOC, 4.3 mg/g), compared with the other tested materials.

Physical filtration of particles and particle-bound organic matter complement soil/bioretention as this layer, accumulated on the sand filter. This acts as an effective filter for urban-sourced organic and metal contaminants (Dittmer et al., 2016). Stormwater concentrations of total suspended solids (TSS) and particulate COD are reduced during infiltration. During dry periods with long residence times, oxygen availability is high, and particulate organic matter is efficiently mineralised and biologically degraded. The long-term removal efficiency of TSS is 90%, COD is 80% and NH4-N is 95%, based on performance of full scale plants under real operational (Dittmer et al., 2016). However, the robustness against extreme wet seasons and cold climatic conditions are not evaluated. In a review article, Tedoldi et al. (2016) shows an efficient accumulation of metals in the upper horizon of soil due to runoff water infiltration. The presence of reactive functional groups and negatively charged surfaces of soil constituents such as organic matter, (hydr)oxides, and clays enhances the sorption of dissolved metals and hydrophobic contaminants.

The German principles and requirements for the handling of stormwater is based on the parameter AFS<63 (fraction of solids < 0.063 mm), (Grotehusmann et al., 2003). The concentration of AFS<63 under normal flow conditions is estimated to 150 mg/L. The fines (< 63 μm) hold the bulk of the pollutants (heavy metals and organic pollutants) transported by stormwater. The discharge concentrations from retention filters are generally AFS<63μ < 5 mg/L, TOC < 8 mg/L, NH4-N < 0,1 mg/L, Zink, Cadmium and Copper are 20 mg/L, 0,02 mg/L and 10 mg/L respectively.

Stormwater sediment contains different particle sizes, ranging from clay to sand and gravel (coarse). The sediment characteristics are key when planning removal and handling of the sediments (through e.g. dredging) as well as management of associated pollution. The pollution present in the sediment, as well as transport of pollution through the sediment depends on the size and density of sediment particles present in the stormwater. Consequently, the geotechnical characteristics, size and density of the sediment are important factors for the design and management of stormwater treatment systems.

2.7.1 Geotechnical characterization of sediment

In general sediments are characterised according to the following parameters: water content, specific density of grains, bulk and dry density, grain size distribution, water permeability, frictional properties, organic and lime content. Sediment is primarily divided into 1) coarse (> 2mm) 2) sand (≥ 63 μm) or 3) silt (≤ 63 μm) and clay (≤ 2 μm). Particle size determines the type of handling and treatment methods suitable, as well as gives an indication of likely contaminants. For instance, likelihood of adsorption of dissolved pollutants onto particles tends to increase with decreasing particle size. Moreover, particles remain in suspension for longer, the smaller they are. Clay particles (≤ 2 μm) in suspension tend to remain there until water motion ceases and then settle very slowly (from several hours to days) to the bottom where they accumulate. Organic content is of interest as since organic matter can be a source of dissolved organic carbon, as well as a transport media for organic and metal pollutants. Highly organic soils usually have a relatively high water content and are compressible with low shear strength. In summary, the characteristics of a sediment are key when planning dredging activities. Once dredged sediment is in suspension, its settlement characteristics are a function of water salinity, turbulence and solids concentration as well as properties of the sediment. Bulking factor is an important parameter when dredging as this describes the dimensionless factor expressed as the ratio between the sediment volume after dredging to that volume of the in-situ sediment. Bulking factor (B) increases with increasing amount of fines and increasing liquid limit values. Bulking factors are generally higher in fresh water than those in salt water.

$$B = \frac{dry\ density\ in\ containment\ area}{dry\ density\ in\ situ} = \frac{\rho_{d,c}}{\rho_{d,i}}$$

2.7.1.1. Freeze and thaw effects on density

Freeze–thaw (F/T) cycles can alter soil physical properties and microbial activity, (Henry, 2007). Soil aggregate stability at high soil moisture decreases, and for the samples with low dry unit weight, the volume of the samples decreases after freeze–thaw cycles (Qi et al., 2008). These changes are accumulated over successive freeze–thaw cycles (Henry, 2007). In a Swedish full-scale pilot, sludge with dry matter content as low as 7 % was exposed to F/T-cycles (Hellström & Kvarnström, 1997). After two F/T-cycles the volume of the sludge decreased by 90 % as its dry matter increased to 60 - 90 %. Wet and loose soil masses can be dewatered through so-called thaw strain (consolidation), in which the sediment consolidate through repeated freezing and thawing, (Knutsson, 2017). This pattern is also shown in Figure 2.4, based on Knutsson (2017), where thaw strain effect increases with decreasing density.

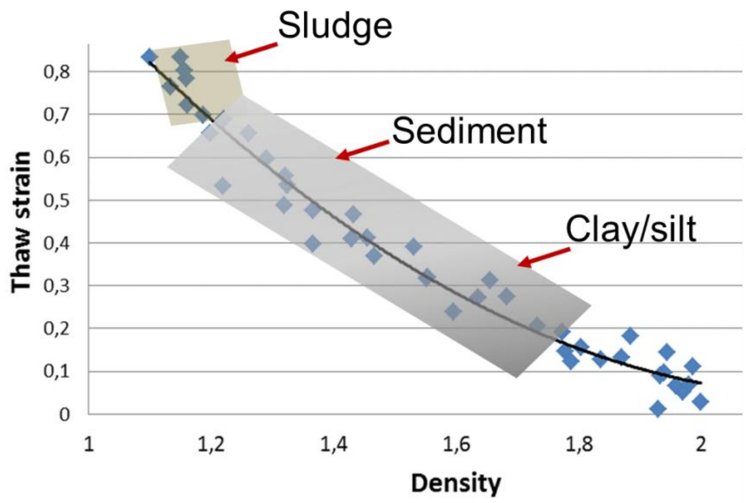


Figure 2.4 Effect of Freeze and thaw cycles on thaw strain and density (Knutsson, 2017).

2.7.2 Particle size and density

Transport of pollutants depends upon the size and density of the particles (sediments) present in road runoff water. Therefore, it is important to consider these factors while evaluating source of pollution in highway runoff and posed management practice to curb the pollution.

Particle size in road runoff varies between 0-2 000 µm (Zanders, 2005). According to a study by Kim and Sansalone (2008) conducted on paved surfaces, the most dominant particle size in road runoff was <75µm, which was reported to be between 25-80% of total solid sediment load. Zanders (2005), indicated that particles from highways showed more than half the material (52%) was smaller than 250 µm, of this 36% was smaller than 125 µm, and 6% was smaller than 32 µm. According to Jartun et al. (2008), grain size distribution in 21 selected samples varied between a median particle diameter of 13 to 646 µm. Generally, high particle bound concentrations of pollutants are associated with smaller particles, (Xanthopoulos and Hahn, 1990) due to large surface-to-volume relationship and the good adsorption properties of especially clay minerals (Krumgalz et al., 1992).

The diameter of particles in sediment in runoff in stormwater traps varies depending on the source (e.g. road surfaces). Median particle diameters of 600–1000 µm have been reported. There is only limited information that is collected today on the sediment quality, the ration of fines divided into sand, silt clay and organic fractions. Kayhanian et al. (2012) reported that 25 % of total particle mass was associated with the < 38 µm fraction in detention basin sediments compared to 47 to 82 % in centrifuged highway runoff samples. Over 97 % of particles (by number) had particle size smaller than 38 µm.

The particle density influences the behaviour in advective transport, sedimentation, filtration, coagulation/flocculation, and re-entrainment. Hence, it is critical to know the density of sediments from road runoff. Many treatment designs, such as those for road runoff settling basins, are developed by using the concept of minimum trapping efficiency. This trapping efficiency is related to the settling velocities of the particles, which are strongly influenced by particle density Cristina et al. (2001).

Studies on sediments found in snow melt and particles from pavements during dry periods of rural roads in Switzerland indicated density between 2.70 to 3.01 g/cm^3 in gradations, except larger particle (850 to 1400 µm) which indicated higher density. The data suggested that the fine particles, such as tire material, were deposited beyond the pavement and shoulder areas because the abraded tires possess a density between 1.5-1.7 g/cm^3 with a particle diameter less than 20 µm (Kobriger and Geinopolos, 1984; Sansalone and Triboullard, 1999). The densities of fractionated particle in runoff generally ranges between 1.5 and 2.2 g/cm^3 and hence it is incorrect to assume a single sand of density of ~2.6 g/cm^3 for all particle size ranges.

Smaller particles are less likely to aggregate naturally and sedimentation without aggregation, takes time. This may partially explain the limited effectiveness of ponds for removing this type of particles. A stud by Kayhanian et al. (2012) showed that morphological characteristics of fine particles ($1 < dp < 10$ µm) were not smooth nor spherical. The particles had negative zeta potentials that typically ranged from −16 to −25 mV, and that zeta potential becomes more negative as particle size decreases. This clearly underlines the importance of longer detention times, which can be compensated by dividing the basins into two segments and capturing and retaining the early runoff in the first basin for a longer period of time.

2.7.3 Pollution associated with stormwater sediment

2.7.3.1 Inorganic pollutants

The most common inorganic pollutants present in road runoff are copper, zinc and lead. Research has shown that the urban dust and dirt in the small particle size range correlates to higher concentrations of pollutants, i.e., heavy metals (Pitt & Amy, 1973; Woodward-Clyde, 1994; Vaze & Chiew, 2004). Generally, these articles conclude that inorganic pollutants found stormwater sediment are associated with a particle diameter below 500 µm, and approximately half of the inorganic pollutants found in stormwater sediment was adsorbed to particles with a diameter between 60 µm to 200 µm.

High concentrations of copper, zinc, and phosphorus were found in sediment with a particle diameter between 74 µm and 250 µm (Dempsey et al., 1993; Vaze & Chiew, 2004). Table 2.6 presents data from a case study in New Zealand. The study shows very high Zn concentration associated with fine particles. Since the sedimentation based BMP only remove larger particles effectively, it is likely that Zn may not be effectively treated using a sedimentation process.

Table 2.6. Total metal concentrations and particle densities determined for each particle-size fraction of road sediment collected over six 2-day intervals, and the average metal concentration of the road sediment sample as a whole (Zanders, 2005).

Particle Size fraction (µm)	Total Metal concentration mg/kg Cu	Zn	Pb	Particle density (kg m^{-3})
0–32	181	2080	316	2140
32–63	197	1695	322	2150
63–125	212	1628	334	2190
125–250	184	1073	251	2330
250–500	85	507	193	2530
500–1000	26	268	323	2540
1000–2000	21	226	36	2390
Whole sample	124	962	249	

Sutherland et al. (2012) studied road sediments to quantify the mass loading of Al, Cu, Pb, and Zn in individual grain size classes (<63 µm to 1000–2000 µm) and the metals partition contributions amongst four sequentially extracted fractions, a) acid extractable, b) reducible, c) oxidizable, and d) residual. Metal mass loading results indicate that particle size < 63 µm dominated almost all fraction loads for a given element. On a concentration basis the road sediments were enriched with Cu, Pb, and Zn. The reducible fraction, associated with Fe and Mn oxides, was the most important component for these elements loading. Aluminium dominates the residual fraction. Increased acidity, especially for Zn, or changes in redox potential, for Cu and Pb, will greatly enhance the solubility of these elements, especially in the < 63 µm grain size class. Environmental planners need to focus their attention on ways to reduce the flushing of fine particles (< 63 m) from road surfaces, as this grain size class accounted for 30–40% of total mass (<2 mm) of sediment.

Camponelli et al. (2010) reported that dissolved stormwater Zn can exceed US-EPA acute and chronic water quality criteria. This was reported in approximately 20% of storm samples and 20% of the storm duration sampled. Also dissolved Cu exceeded previously published chronic criterion in 75% of storm samples and duration and exceeded the acute criterion in 45% of samples and duration. However, the majority of sediment Cu had low bioavailability while Zn was substantially more bioavailable.

Identification of chemicals exerting toxic effects remains a challenge and, consequently, direct toxicity testing of sediment may be more effective. Circumstantial evidence points to road runoff sediment as a major contributor to sediment toxicity.

2.7.3.2 Organic pollutants

Organic pollutants are common in road runoff. Two most important classes of organic compounds detected in road runoff are semi-volatile organic compounds and volatile organic compounds. However, semi-volatile compounds are most common, and it includes oil, grease, polycyclic aromatic hydrocarbons, and total petroleum hydrocarbon. Volatile organic compounds such as toluene, benzene and xylene are less common and more associated with industrial sites. (Lopes & Dionne, 1998). The semi-volatile compounds are used as lubricants in vehicles, where they are also released. The concentrations of these compounds are low, typically less than 10 mg/L, however, the concentration varies depending on location and traffic intensity. For instance, concentrations are higher in parking lots.

Quantification of polycyclic aromatic hydrocarbons (PAHs), in particulate fractions in stormwater from road runoff, was studied by Nielsen et al. (2015). This study showed that High-Medium weight (HW-MW) PAHs are found in particulate fractions, while low- and middle weight (LW-MW) were found in dissolved fractions. The highest PAHs concentrations were associated with high TSS levels and presence of nano-sized particles (10 nm), and 45% of the PAHs in stormwater were present in the colloidal and dissolved fractions. The PAHs identified in stormwater in the particulate fractions and dissolved fractions were hydrophobic. The results show the importance of developing technologies that both can manage particulate matter and effectively remove PAHs present in the colloidal and dissolved fractions in stormwater. The amount of PAHs adsorbed to the mixture of particles with iron and humic acid were the highest, while PAH adsorbed less to the inorganic Fe particles.

2.7.3.3 Nitrogen and phosphorus

Nitrogen and Phosphorous found in runoff is mainly derived from atmospheric fallout and fertilizers from surrounding land use. Al-Rubaei et al. (2016) reported a removal of Cd, Cu, Pb, Zn, TSS and TP between 89 and 96%, whereas TN were reduced by 59%. More than 60% of the total phosphorus in the runoff is attached to sediment with a diameter between 11 µm and 150 µm, and 40-50% was adsorbed onto particles with a diameter between 11 µm and 53 µm. Similarly, most of the total nitrogen is attached to particles in the size range of 11 µm to 150 µm. Kayhanian et al. (2012). Since, nutrients are attached to fine sediments it is important to consider management and technology which removes fine particles.

2.8 Sediment handling

As part of the management and maintenance of a stormwater treatment system, dredging is generally carried out after 15-20 years over the lifetime of a stormwater treatment system in order to remove the saturated sediments and minimize the risk of contamination escaping to the surrounding environment.

2.8.1 Hydraulic and mechanical dredgers

A typical procedure during a dredging project comprises: classification, dredging, dewatering and landfilling. It has been estimated that one ton (dry weight) of sediment produces 3-10 tons of waste, due to its water content, depending on how the sediment is captured and processed. Costs of emptying a pond and handling its sediment generally increase with higher content of fine particles and organic matter.

There are two main types of dredging techniques: hydraulic and mechanical, (Eisma, 2006). The simplest form of hydraulic dredger is the suction dredger. From a floating pontoon, the suction pipe is lowered into the sediment and by mere suction action of the dredge pump, sediment is removed. Only relatively loosely packed granular or silt material can be dredged with this equipment. After raising the sediment through the suction pipe, the sediment is hydraulically discharged though a pipeline. Backhoe dredgers are mechanical conventional hydraulic excavators that are mounted on a pontoon or placed on land. The sediment is excavated by the crane's bucket, which is then raised above the water by the movement of the crane arm. Table 2.7 compares the two techniques.

Table 2.7 Comparison between hydraulic (Hyd) and Mechanical (Mech) dredging techniques, based on Eisma (2006) and Herbich (2000).

Accuracy of the excavated profile	Hyd	Relatively uncontrolled, normally an irregular pattern of pits is created.
	Mech	The precision is good as the cutting edge of the successive buckets passes the same depth. Often used where accuracy is vital.
Increase of suspended sediments	Hyd	Depending on the difference between jet flow and suction flow it has a low tendency to re-suspend sediments.
	Mech	Some additional suspended sediments are released during the raising of the material in open buckets as they move at a relatively high velocity through the water. This can be limited by reducing the velocity of the bucket.
Mixing of soil layers	Hyd	Less suitable for selective dredging.
	Mech	Can easily cut relatively thin layers, avoiding a mixing of different sediment layers.
Creation of loose spill layers	Hyd	Free and relatively uncontrolled flow of material to the suction mouth, and consequently considerable spill is to be expected.
	Mech	Almost all the sediment loosened by the bucket is carried away. Minor risk that a spill layer remains.
Dilution/ increase in volume	Hyd	Water is added to the sediment for transportation purposes. Depending on the sediment type, added water is typically 80% of the total weight. The increase in volume is due to an increase in void ratio and water content of the sediment. Bulking factor is a dimensionless factor expressed by the ratio of the volume of the sediment after dredging to that volume of the sediment in situ.
	Mech	There is no need for transport water as the sediment is raised, however, when the buckets are not filled with sediment, quantities of water will be added. Water content is 30-50%.
Output rate	Hyd	between 50-500 m^3/h
	Mech	between 50-1500 m^3/h

2.8.2 Risks and considerations when dredging

According to Pourabadehei and Mulligan (2016) uncontrolled re-suspension could remobilize weakly bound heavy metals into overlying water and pose a potential risk to aquatic ecosystems. Shallow water with contaminated sediment is at risk of uncontrolled re-suspension. Ex-situ remediation also requires dredging of sediment, which could increase the risk of spreading contaminants.

Changes in the leachability of metals from dredged canal sediments during drying and oxidation were studied by Stephens et al. (2001). Metal leachability increased over the first five weeks of drying and then subsequently decreased between weeks five and twelve. These results were combined with sulphide/sulphate ratios, which showed a decrease as the sediment dried. Most metals (except Cd and As) showed a redistribution from residual phase into more mobile phase as the sediment dried and oxidised. Metal leachability was strongly correlated with sulphide/sulphate ratio with leachability normally increasing with decreasing ratio.

In dredged anoxic canal sediments, rich in sulphur and organic matter, it seems likely that the metals will be present predominantly as metal sulphates adsorbed to metal sulphide surfaces or they may be adsorbed to organic matter. As the sediment dried and oxidised the metal sulphides were probably oxidised to metal sulphates. Metals that were bound to the surfaces of sulphides within the anoxic sediment may have been released and become adsorbed to the newly formed sulphate surfaces and or precipitated as oxides. In some cases where the metal oxides are less soluble then the corresponding metal sulphides availability may be expected to decrease.

3 BMP – Legislation and practice

Within this chapter we present a compilation of current legislation for stormwater management from four countries; Sweden, Norway, Germany Austria and Switzerland and compares legislation with current practice in respective countries. Legislation governing stormwater management was compiled by means of a review of available guidelines, handbooks, ordinances, regulations and other relevant documents for each country.

Practical experience was surveyed by means of interviews conducted either by telephone or in person. All interviews were conducted following the same questionnaire supplied to the participants in advance to allow for them to prepare (Appendix A (in Swedish)). Nine participants from the Swedish Transport Administration and seven from the Norwegian Public Road Administration were interviewed by telephone. Two experts from the German Federal Highway Research Institute (BASt) were interviewed in person during a visit to Germany. The practical experience from Austria described below, is derived from survey answers provided in writing by one single interview participant from ASFINAG's (Autobahn- und Schnellstraßen-Finanzierungs-Aktiengesellschaft) division of Operational Maintenance Services unit for Water and Environmental Protection.

The survey answers provided were used to analyse similarities and differences in road runoff management in the selected countries. The analysis focussed on three topics: 1) Which factors determine the chosen type of BMP, 2) BMP design criteria and dimensioning, 3) follow-up of BMP performance and functionality.

3.1 Sweden

3.1.1 Legislation

In Sweden, road runoff and drainage from road constructions is commonly infiltrated via road shoulders, embankments and open trenches. When infiltration is not possible or prohibited road runoff is collected for treatment via culverts and open trenches. Since the 1990's, wet stormwater ponds have been the most common facilities for centralised treatment of road runoff. Although the number of newly constructed ponds is declining, sedimentation ponds still account for circa 75 % of the approximately 800 centralised treatment facilities the STA (Trafikverket) operates (Vägverket, 1998; Trafikverket, 2014). Responsibility for maintenance of these facilities is distributed across the six regional offices of the STA. Stormwater management must comply with the Swedish Environmental Law (Miljöbalken).

The STA has published several handbooks that deal with the management of road runoff. The main focus of these handbooks lies on wet sedimentation ponds, infiltration ponds and vegetated filter strips swales. However, no recommendations for when to use which specific treatment facility are provided by the STA. Treatment design rather seems to depend on case-specific recommendations and environmental, hydraulic, economic and aesthetic demands from the local authorities.

Contrary to the situation in other countries, annual average daily traffic (ADT) is not a factor that regulates whether runoff requires treatment in Sweden. ADT is currently only used to determine the need for precautionary containment measures for accidents, involving hazardous substances. Roads with an ADT below 2 000 are generally not considered to need an accident based precautionary treatment system. An exception exists for roads nearby watersheds that need protection and for roads traversing drinking water protection areas. The latter exception concerns runoff from roads > 200 ADT of heavy traffic (Trafikverket, 2011). STA operates a spatial database of the Swedish roads and railways network, used to identify and handle runoff risks around existing infrastructure and to plan maintenance and construction work around existing treatment facilities (Gerenstein, 2016).

The conducted review found nine documents outlining recommendations and requirements for handling road runoff and road drainage water, see Table 3.1. Most of these are technical documents providing guidelines on the design of trenches, ponds etcetera for the purpose of flood retention. There is also a handbook dealing with inspection and maintenance of open stormwater treatment facilities, (Trafikverket 2015:147). However, as mentioned above, there is no prescribed decision-making process to determine when a treatment facility is required. Generally, water retention and sedimentation are considered to provide sufficient treatment to prevent negative impact on water quality downstream of the treatment facility. Total suspended solids (TSS) is mentioned as an important criterion for treatment in some of the documents. TSS is, however, not actually considered as a factor in treatment design that instead is entirely focused on flood retention.

The lack of recommendations describing when to use which kind of treatment facility is currently being addressed by STA and a new directive is under consideration.

3.1.2 Policy documents - Guidelines

STA's advice on handling runoff water is described in: "Stormwater - Advice and recommendations for the selection of environmental actions, STA document Trafikverket 2011. The STA and its consultants use this publication only internally. Other technical documents "technical requirements for dewatering" (Trafikverket, 2014a) and "advice for dewatering" can be found in (Trafikverket, 2014b). These documents are mainly used by consultants. There is also a handbook for maintenance of open stormwater facilities "Open stormwater facilities – A manual for inspection and maintenance 2015:147". It is an update of "maintenance of open storm water facilities" in Trafikverket (2008).

In addition to the Swedish Road Administration's own documents there is a "Draft guideline from 2009 for stormwater discharges" drafted by a stormwater network of consultants and officials from different municipalities in the Stockholm area. This document has a direct influence on how municipalities are reasoning although it has never been certified. The document provides guidance on management of stormwater depending on the sensitivity of the receiving waterbody. In the absence of other governing documents, it has since been used as a reference. At least three municipalities have also made their own guidelines in recent years.

Of the interviewed specialists only one performed investigative work and had thus read some of the documents. The remaining respondents were, however, at least aware of the documents existence. In general, there are many documents regarding road runoff on the STA website.

It was the implementation of the Swedish Environmental Law (Miljöbalken) in 1999 and its subsequent environmental quality standards that first introduced road runoff management from a water quality perspective. The "Weser judgement" from the European Court of Justice (C-461/13, 2015), Friends of the Earth Germany versus the Federal Republic of Germany) has and will continue to have a considerable impact on road runoff management (2.15). The verdict states that no deterioration of any of the parameters used to describe a waterbodies ecological or chemical status can be accepted by new development. Permission for projects that deteriorate even a single parameter is to be denied. Even projects that do not directly deteriorate status but could jeopardize future improvement of ecological or chemical status cannot be given permission.

Table 3.1. STA publications that provide recommendations and requirements for handling road runoff and road drainage water.

Requirements	2014:0045	Drainage – technical requirements for drainage
Recommendation	2011:112	Stormwater – advice and recommendations for environmental action plan
	2014:0046	Drainage
	2014:0051	Drainage – Design and dimensioning
Handbook	2013:135	Surface and ground water protection
	2015:147	Open stormwater treatment plants – Inspection and Maintenance
Publication	2003:188	Stormwater ponds – Investigation of function and efficiency
	2006:115	Stormwater ponds – Sampling, sedimentation and hydraulic
	2008:30	Maintenance of open stormwater treatment plants

3.1.3 Practice

STA's most common approach to stormwater management is infiltration in road shoulders, embankments and open ditches. Most existing centralised facilities are aimed at spill containment with accidents involving hazardous substances. When facilities aimed at preventing negative impact on water quality are demanded, the demands often originate from municipalities and county boards and are based on site-specific conditions and ADT.

The current STA document in use to determine the need for stormwater treatment is: "Stormwater -Advice and recommendations for the selection of environmental actions (STA, 2011:211). According to the guidelines therein the project manager, in consultation with an environmental specialist, decides on the type of treatment facility on a case-specific basis.

Prior to 2011 municipalities and county boards proposed or demanded treatment facilities based upon their individual interpretation of guidelines and legislation. The resulting implementation of stormwater management would vary accordingly from case to case and between different municipalities.

Planning of operation and maintenance of treatment facilities

Contrary to previous practice, management and maintenance are currently taken into account when planning a new facility. The importance of accessibility for maintenance activities such as debris removal, vegetation maintenance and periodic dredging is widely recognised and access roads are included in the design already at the planning stage. Older facilities that lack such access roads and maintenance plans, are very often extremely laborious to maintain.

Many of Sweden's 800 roadside stormwater ponds have been constructed after 2000. For one specific motorway 50 stormwater ponds were built in early 2000. In this case the local environmental authorities set strict requirements mandating ponds for treatment of road runoff. However, management- and maintenance plans were not drafted during planning and construction stages. These plans were added several years later.

Documentation and handing over to the proprietor

When a treatment facility is completed it is handed over to the operations division together with management plans and possibly operational and maintenance instructions. There is a mandatory procedure in place since May 2016 that stipulates the entry of background documentation into the NVDB (National Road Database) before commissioning. Prior to 2016 such entry was voluntary. The documentation entered into the system must contain an environmental report.

In the greater Stockholm region background data is even entered into the local maintenance database called Maximo. The operating contractor can gain access to relevant information in Maximo and upload new information about a facility before handing over the facility to a STA project manager. Entered facility information is available to interested entrepreneurs during the procurement process for maintenance contracts.

Construction contracts that extent over the building phase and include a ten-year period of maintenance by the contractor have become more common. During 2014 an inventory of all treatment facilities for road runoff was conducted (Trafikverket, 2014). Inventory results were entered into the NVDB. There is, however, large variation in the level of detail of the entered information. Some facilities are described comprehensively, whilst other are only registered with position coordinates. New facilities are in general better documented in the database.

Operation and Maintenance

The survey conducted included two of STA's six regional offices. The survey participants that answered questions about operation and maintenance were two project managers with operational responsibility and one external consultant.

All facilities covered by the survey were constructed in conjunction with the construction of new roads, not during upgrades of existing roads. The majority of facilities are retention ponds from the period 1999-2006. Survey participants from STA's Stockholm regional office have even included a number of facilities still under construction in their answers. None of the interviewees has been involved in the planning stages of the facilities they are operationally responsible for.

Control and enforcement

Drawing general conclusions about treatment facility functioning is difficult because of the number of treatment types in use and their site-specific characteristics. Modern treatment facilities for Stockholm roads with high ADT are inspected and sampled several times per year. Inspection and sampling results are compared with an approved control plan. Older ponds along roads with lower ADT are not checked as often. For some treatment facilities maintenance information is lacking in the system altogether.

Operating contracts include the responsibility to conduct regular inspection and maintenance of the facilities. In some regions controls of hydraulic functioning and sampling of effluents are not carried out on a regular basis. In Stockholm region, the operating contractor has full access to all data in Maximo and must even upload inspection protocols for follow-up by the project manager. Inspection requirements, however, vary considerably between involved municipalities, with some requiring sampling protocols and results or even sampling themselves and others having no demands at all.

Ongoing maintenance

The entrepreneur responsible for maintenance of stormwater facilities is typically the same contractor that is responsible for other maintenance such as accident debris removal, salting and snow removal and clipping of road shoulder vegetation. However, for maintenance requiring special expertise such as sediment dredging subcontractors are commonly used. In the Stockholm region, all sampling of treatment facilities is performed by one single entrepreneur.

Maintenance plans describe required maintenance activities and their required frequency. Regular maintenance of stormwater ponds includes cleaning and clearance of in- and outlets, removal of vegetation, mowing of slopes and adjacent green areas etc. The most commonly observed recurring problem are ponds becoming overgrown, debris accumulating and soil erosion. It is part of the contractor's responsibility to correct these problems.

If operators discover major failures unrelated to regular maintenance that will report to STA and carry out the additional measures needed to solve the problem. Dredging to remove accumulated sediments is also considered as additional maintenance. The fact that older facilities often lack access roads (see above) often aggravates sediment removal, especially when heavy machinery is needed.

Removal of accumulated sediments

Experience of dredging is very limited and appears to vary between regions. In the Stockholm region six stormwater ponds have been dredged during the last eight years, whereas in the lake Mälaren region no dredging took place during the same interval.

According to maintenance plans sediment accumulation is controlled regularly in order to plan maintenance and dredging. Sediment removal is often planned at least two years in advance. In Stockholm, the contractor is required to draft a restoration plan before maintenance work can commence. Such plans include requirements to seal of pond outlets in order to prohibit stirred up sediments from reaching downstream waterbodies. There is currently no standard practice in place for dredging and dewatering accumulated sediments. Site-specific conditions have significant impact on the methods chosen. The contractor is responsible for collecting sediment samples, assessing level of contamination, and classification of sediments according to waste categories. Sampling results and assessment are generally summarised in a written report.

Costs

An average sized pond in Sweden produces about 100 m^3 sediment. Stormwater basins accumulate similar volumes. In Södertälje municipality, 30 kilometres southwest of Stockholm, about 400 m^3 of sediment was dredged from a large stormwater pond during the early 2010's.

Sediment removal, dewatering and subsequent transport are estimated to constitute about half of the total operational costs for dredging. The other half consists of fees for sending the sediment to a landfill. The cost for dredging a stormwater retention basin for a tunnel in Stockholm are estimated (in 2017) to be approximately SEK 3 000 per m^3 of sediment removed. Landfilling fees vary between SEK1 000-1 500 per ton of sediment. In terms of volume this represents a price interval from SEK 1 300-2 000 per m^3.

In general costs for sediment removal and subsequent pond restoration vary widely, based on pond type and site-specific conditions. Factors such as the type of equipment required, availability of access ramps and whether or not the pond can be bypassed or redirected during maintenance severely impact the expenses. Facilities that cannot be bypassed will, for example, lead to a much higher water content in the removed sediments. Dewatering on site is an additional cost. When dewatering is not an option, the high water content will have a profound effect on the landfill fees due to the extra mass.

Knowledge gaps

- Environmental legislation and climate change issues will have an increasing impact. To prepare for this, cooperation and exchange of knowledge with other countries is of key importance.

- Storm water facilities should be given an appropriate level of maintenance and all conducted maintenance should be documented in detail. The documentation will facilitate the decisions that prioritize which measures are needed and where.

- It is of key importance to emphasize that abiding by the EU water framework directive is compulsory. The fact that no deterioration of water quality can be tolerated must be considered from the early planning stage. All measures taken must aim at the prevention of impaired water quality and their effect must be verifiable.

- Opportunities to coordinate the procurement of restoration of stormwater ponds need to be explored. Many facilities have approximately the same age and there are possible synergy effects in coordination. As restoration of a stormwater pond is a major measure, it must have a long-term plan based on information collected during its operational period. Supplementary questions have to be answered in forehand. Choice of method, dredging and pumping or excavating, dewatering, need of land-filling should be addressed.

3.2 Norway

3.2.1 Legislation

As for many other countries, the strategies for managing road runoff have changed during the last decades in Norway. Before the 1970s the main focus was on managing water quantities (flood prevention) whereas today other factors, such as aesthetics, water quality and ecology, are also taken into account (Håøya & Storhaug, 2013). The Norwegian NPRA has more than 150 treatment facilities for road runoff, where sedimentation ponds are most common (COWI, 2012).

Just as described for Sweden above, there are no general design criteria or guidelines that determine whether runoff should be treated or not. The decision to treat stormwater or not is site specific and is often based on experience from previous projects. Important factors that weigh in on the decision are receiving water vulnerability and ADT (Ranneklev et al., 2016). There is an ongoing NPRA project that aims to establish guidelines that define whether or not road runoff requires treatment. Currently, Norwegian survey participants indicate that existing roads will be upgraded with treatment facilities in the near future.

For newly constructed roads the need to treat runoff is assessed during the environmental operating plan process and needs to be evaluated and approved by the authorities.

The NPRA has developed a technical handbook (Vägdirektoratet 2014) for road constructions. Its 500 pages are mostly related to road building. Chapter 4 deals with stormwater management and dimensioning of treatment facilities. Section 403.4 describes design and dimensioning of treatment facilities for handling road runoff and road drainage water, see Table 3.1. Publication N200 does, however, not provide any tools to help determine the level of treatment required. Figure 3.2 gives an example of a stormwater treatment design.

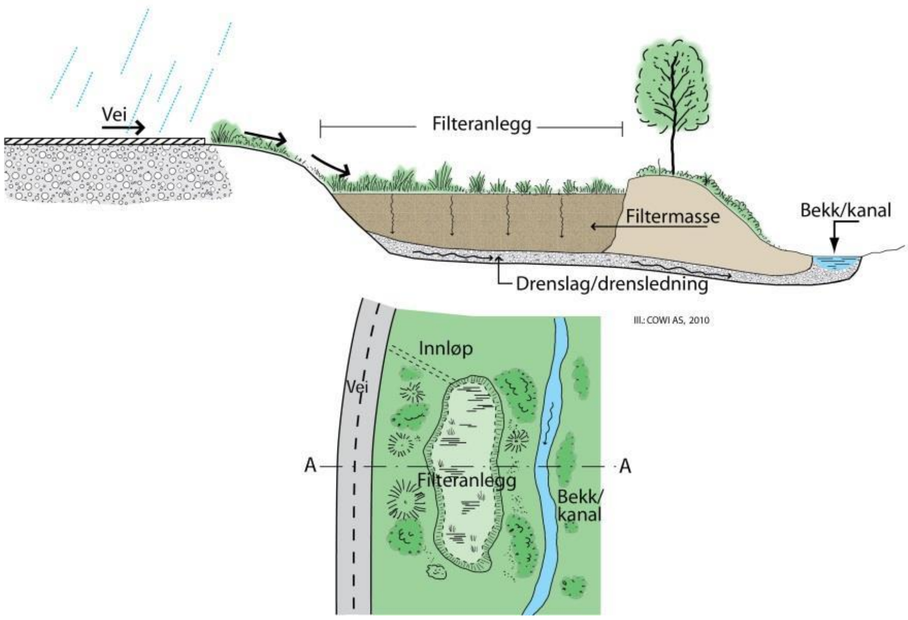


Figure 3.1. Design of infiltration filter for treatment of road runoff. From Håndbok N200, Figure 403:6.

During the process of building a road, environmental issues are documented in a document and external environment plan (Ytre miljøplan, also known as YM-plan in Norwegian). External environmental plans are regulated in the "Handbook R760 Control of road building projects". An external environmental plan describes the actual building site in terms such as nature, water, culture, landscape design and climate. This document is updated as the building process proceeds, and contains more and more details as the project progresses. Even contractors are supposed to prepare an external environment plan during the planning stage. After completion of the building phase the document is passed on to those responsible for operation and maintenance of the road, see figure 3.2. An external environment plan has the same function as an environmental impact assessment (EIA) has in Sweden. One major difference is that an external environmental plan does not need to describe other location management options.

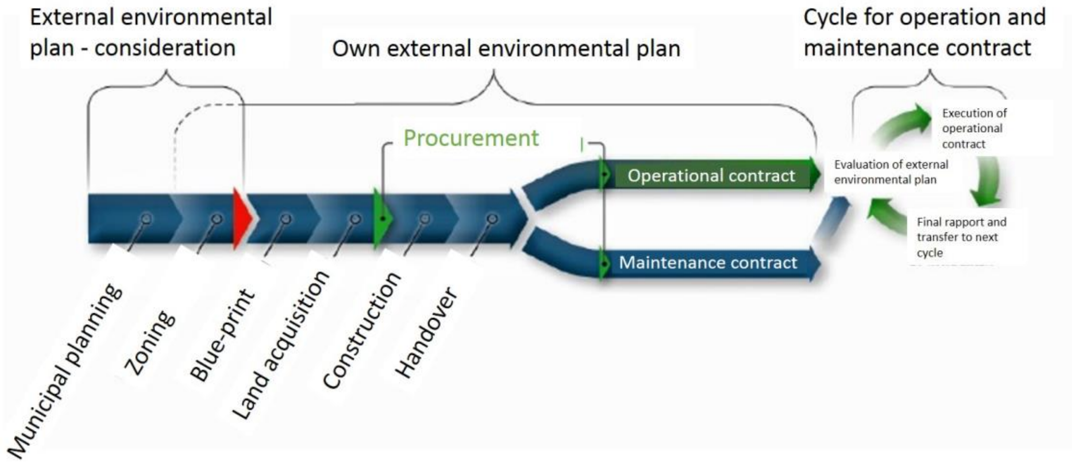


Figure 3.2. Planning process for construction and operation of roads under the auspices of the Norwegian Public Roads Administration. (Ranneklev et al 2016.).

The NRPA research and development program Nordic Road Water (NORWAT) that conducted between 2012 and 2016 has developed new guidelines for road runoff management. Three reports from the research project are listed in Table 3.2. Two of these describe the state of stormwater treatment facilities in Norway today.

A new guideline for management and treatment of road runoff is under development and the aim is to include these in the new handbook N200. The proposal is outlined in NPRA report Nr. 597 "Water reservoirs vulnerability to road runoff during building and operational phase". A scoring system that will help determine the level of treatment required on is based on traffic intensity, sensitivity of the receiving water and other interest is under development, see Figure 5.1.

In the proposal ADT is used as a first parameter in the decision scheme that determines treatment needs (Figure 3.3). At traffic intensities up to 3000 ADT, there will be no requirements to treat road runoff in addition to infiltration in road shoulder. Between 3000 – 30 000 ADT, an assessment of treatment will be conducted based on the mentioned scoring system. The biodiversity of the receiving waterbody is assessed based on the Habitats Directive. It is classified as having either low, medium or high vulnerability. Vulnerability is defined as the receiving waters capacity to return to its prior condition with or without restoration. At traffic intensities over 30 000 ADT, road runoff water is regarded to carry heavy pollutant loads and is always treated. It is at present already mandatory to treat stormwater and excess water from tunnel washing separately from other stormwater. Tunnels are washed four times per year. Accumulated sediments together with the washing water is typically pumped to a closed basin for treatment.

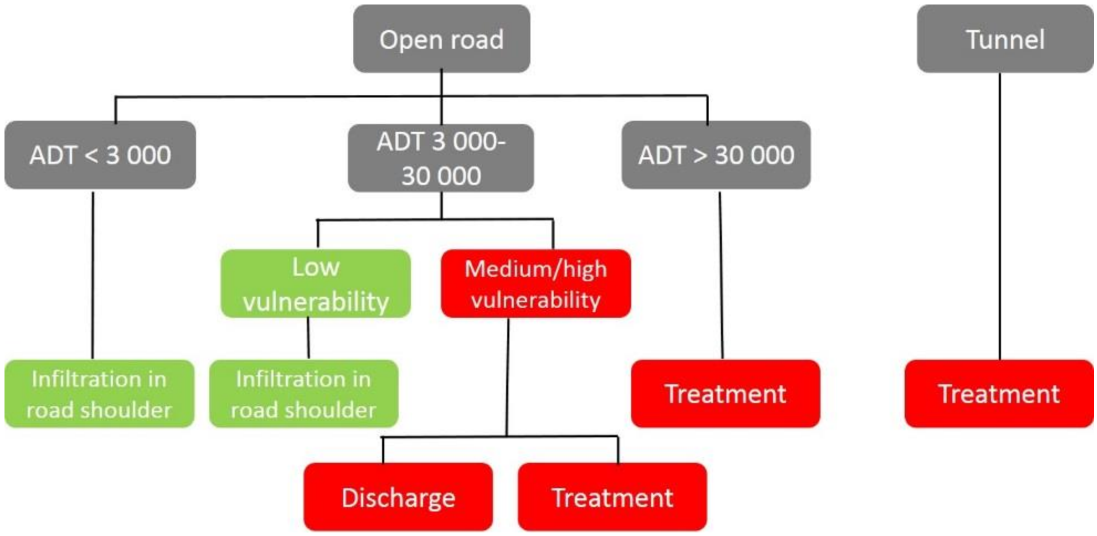


Figure 3.3. *Suggestions on how the storm water from different types of roads should be managed, based on ADT and water sensitivity (From Nr 597).*

Stormwater treatment is mandatory whenever there is a risk for groundwater pollution in drinking water protection areas. The choice of treatment is case-specific and based on traffic intensity and an assessment of the receiving water. Environmental Quality Standards (EQS) were established for Norwegian waterbodies in 2016 to avoid deterioration of water quality. The development of the regulatory framework has contributed to more frequent use of treatment facilities and to greater demands for stormwater treatment before discharge to surface or groundwater.

Table 3.2. Norwegian recommendations and requirements for handling road runoff and road drainage water.

Publication type	Number	Reference
Handbook	N200	Handbook N200 for building roads, the NPRA (June 2014)
Handbook	R760	Handbook R760 Control of road building projects, the NPRA (June 2014)
Published report	Nr. 597-2016	Water reservoirs vulnerability to road run off during building and operational phase, Norwat (May 2016)
Research Publication	212-2013	State of the stormwater facilities in Norway, NPRA (2013)
Publication	650-2016	Inventories of facilities in region, Sor (2016)

3.2.2 Practice

Typical facilities for treatment of road runoff in Norway are stormwater ponds and retention basins. A smaller number of infiltration facilities and wetlands are also in service. Inlets and outlets of all facilities are placed to ensure functionality even under cold climatic conditions.

The choice of stormwater treatment strategy is made by the project manager for road construction. The proposed solution is presented to the County Agency (Fylke) which regulates when treatment is appropriate and by what method. Municipalities are also involved when stormwater is led into their stormwater system. The demands are set in a regulation plan, which is legally binding.

Operation and maintenance

Two regions were covered by the interviews, Ostfold Nord and Vestfold Syd. One of the regions operates 15 sedimentation ponds and one infiltration pond. The other region has 21 sedimentation ponds and a number of retention basins. Sedimentation ponds are often constructed in two parts; a forebay for initial sedimentation of coarse particles and a main compartment for sedimentation of finer particles.

All mentioned treatment facilities are relatively new, the oldest are from 2005. Three facilities are under construction and not yet in use. All treatment facilities have been built along newly built road stretches. In the region with 21 facilities, six were constructed in 2014, nine in 2012 and the rest during 2009. The treatment principle of all facilities is roughly the same, but the mechanisms used differ. Generally, facilities that receive tunnel wash water are more complex. Such facilities need to be equipped with a volatile substance separator in order to be able to receive oil spills from accidents.

Norwegian survey participants cite that according to their experience with monitoring stormwater facilities (mainly ponds), operation and maintenance has historically not been a priority during planning and construction. Today, an effort is under way e to improve this situation. It is, for example, recently become mandatory to build access roads and ramps that facilitate access for service vehicles.

Handing over to the proprietor

Nowadays those responsible for maintenance are involved in the early stages of a new project. They can participate and discuss different solutions and principles, although they are not involved in the finer details of the design process. When a new treatment facility is handed over to the proprietor, a routine operation manual, instructions, drawings and technical description of the facility will follow. These instructions are drafted when the facility is designed and constructed. An External Environment Plan is also included. In the national database all facilities are registered with the object name, but the database does not include documents and operating instructions.

Ongoing maintenance

The entrepreneur that is rewarded the road service contract after construction gets access to all relevant documents, such as management plans, via the procurement procedure. The contract covers all "conventional" road maintenance activities such as salting, snow removal, accident debris removal and clipping of shoulder vegetation as well as maintenance to and oversight over stormwater facilities. Details of the maintenance activities to be conducted are described in the contract. Regular maintenance to stormwater facilities includes cleaning and mowing of grass, cutting vegetation two times a year, clearance and maintenance of access roads to the facility and control of security, such as locks and fences. Problems with maintenance are primarily of a technical character, such as problems with valves, and blocking of inlets and outlets. Sediment removal and maintenance of hydraulic controls, such as valves, are considered as additional work that require authorization by the road administrator’s project manager before work can commence. Subcontractors are commonly hired for activities requiring specialist expertise, such as dredging and sediment handling and disposal.

Operating contracts are valid for a five-year period. The contractors are supposed to control the treatment facilities at least once a year. Forebays are typically emptied of coarse sediments on an annual basis. After sediment removal a check of the facilities functionality is performed. This check consists of a visual assessment of sediment accumulation and potential irregularities in the facilities functioning. Effluent flow rates and contaminant loads are not sampled to control functionality

One of NPRA regional offices compiles an annual report on the treatment facilities, including test results and other information; a practice not standard in other regional offices. The local environmental authorities do not require reports and have not performed supervision in the operational regions included in the interviews.

Removal of accumulated sediments

Sediment removal from retention ponds and basins is performed in accordance with pre-existing operational instructions. Several forebays the survey participants are responsible for have been dredged annually. In order to investigate seasonality of sediment accumulation dredging has been performed during different seasons. Main compartments are dredged less frequently, and the decision carry out dredging is based on an assessment of visible parameters, such as sedimentation and flow patterns. Sediment accumulation rates vary considerably between facilities.

Depending on circumstances, sediment accumulation was removed either by common excavators or by hydraulic dredgers. In some cases, the dredged sediment was dewatered on site. A typical recurring problem is that the heavy machinery required for dredging cannot reach the treatment facility due to lack of access ramps and poor geotechnical conditions that would lead to soil compaction under these vehicles.

Costs

The stormwater facilities covered in the survey varied from 200 to 1500 m^2 in size and construction costs varied between NOK 500 000 and NOK 2 000 000.

Dredging example 1: NOK 1500 per cubic meter of removed sediment at an estimated volume of 10 – 20 m^3.

Dredging example 2: NOK 1600-7500 per ton of sediment (represents NOK 2000 – 10 000 per m^3). In this case only one ton is removed at a time. The facility collected stormwater from seven km along a four-lane road including a tunnel.

The survey participants argued that it is difficult to generalise on the number of treatment facilities needed per kilometre of road. Site-specific variation in, for instance, number and length of tunnels, topography and receiving water status makes generalisation difficult. The following two examples do, however, provide some rough estimate on required number of treatment facilities per stretch of road:

- 20 km of four-lane road, 8 retention ponds
- 10km of four-lane road, 10 retention ponds

Need for research

- More knowledge on how road salt affects stormwater facilities.
- Much attention has been given to dimensioning all installations as accident protection measures. Follow-up on how these installations are actually working is required
- Stormwater pond design is perceived as too complicated and too variable. A standard solution applicable across sites would be much simpler and easier to maintain. Functionality would be easier to test and ascertain, which would facilitate facility management.
- It is important to gain more information about the use of chemicals and how they can affect stormwater facilities function. For example, the use of environmentally friendly detergents for tunnel washing.
- Important to continue the cooperation through the Conference of European Directors of Roads (CEDR)
- Awareness and demands on the treatment and handling of larger amount of stormwater quantities are increasing.
- There is a need for international cooperation in research and development between the NPRA and similar agencies from other countries facing the same challenges with stormwater management.

3.3 Germany

In Germany, the most commonly used treatment of road runoff is local infiltration in the road shoulder and embankment and is used along more than 90 % of all roads outside of settlements. Typically, roads have stormwater collection ditches along the embankment but as the largest part of annual precipitation falls in the form of rain events with intensities lower than 15 l/s ha, road ditches are mostly dry. Rainwater that is not collected in a stormwater system or treatment facility is not regarded as wastewater not considered to require treatment.

3.3.1 Legislation

Legislation for handling road runoff within cities and settlements falls under the responsibility of the DWA (German Association for Water, Wastewater and Waste). The current legislation is described in document DWA M-153 (DWA, 2007) soon to be replaced by DWA-A 102/BWK-A 3 (DWA, 2016). The draft version of DWA A-102 defines the necessity for treatment according to the expected annual load of suspended solids smaller than 63 µm (AFS_{63}), according to Table 3.3.

Table 3.3. Treatment required according to annual load of suspended solids < 63µm (AFS63).

AFS_{63} transport (kg/ha per year)	Pollutant load	Action
< 280	Insignificant	Treatment generally not required
280 - 530	Moderate	Treatment required in most cases
> 530	High	Treatment required for all cases

Where AFS_{63} transport falls below 280 kg/ha per year, the pollutant load is considered insignificant and treatment is not required. AFS_{63} loads between 280 and 530 kg/ha per year are considered as an indicator for moderate levels of pollution and treatment is required in most cases, while AFS_{63} loads above 530 kg/ha per year indicate high pollutant loads that require treatment.

The legislation for road runoff outside of settlements is described in the "Guidelines for the installation of road drainage" published by the Road and Traffic Research Society (Forschungsgesellschaft für Strassen und Verkehrswesen, FGSV) (FGSV, 2005). The flow chart in Figure 3.4 visualizes the decision process to determine the required treatment after RAS-EW. A new version of RAS-EW is currently being developed and is expected to be published 2019. The treatment principles to be described in the new version will, according to the survey participant at BASt, remain largely the same as in the 2005 version but more clearly defined. Emphasis will be given to the importance of infiltration even under conditions where only a part of the runoff volume can be infiltrated.

For road construction in sensitive areas, such as groundwater protection areas and susceptible ecosystems, collection and centralised treatment of stormwater is required, following the RiStWag, "Guidelines for constructional measures on roads in water protection areas", (BASt, 2002). Maintenance of stormwater treatment facilities is not regulated but a set of recommendation are available and in widespread use, H KWES; "Notes on the control and maintenance of drainage systems on roads" (FGSV, 2011).

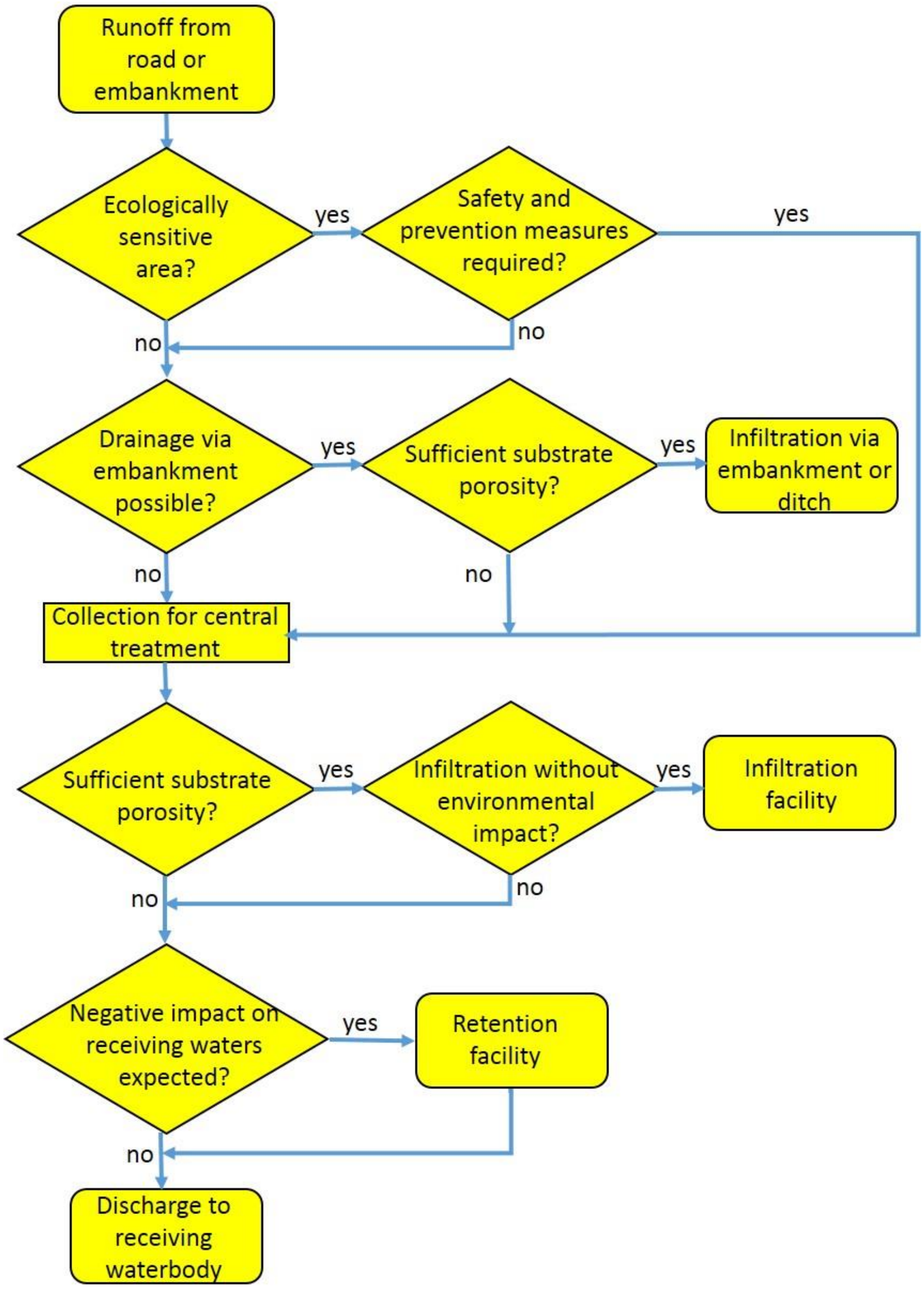


Figure 3.4. Flow diagram to determine the type of runoff treatment required outside settlements in Germany. Source: Regelwerk zur Strassenentwässerung ausserorts, RAS Ew, 2005, Road and Transportation Research Association (FGSV).

The need for treatment following RAS-EW and RISTWAG is categorised according to traffic intensity, whereby both traffic emissions and risk for accident with hazardous substances are taken into consideration. The required treatment categorised according to ADT is listed in Table 3.4.

Table 3.4. Treatment of stormwater from "semi-motorways" according to Annual Average Daily Traffic intensity (ADT).

ADT (vehicles/day)	Pollutant load	Action
< 2 000	Low	Released to surface or groundwater without treatment
2 000 up to ≤ 15 000	Moderate	Treatment generally required prior to discharge
15 000	High	Stormwater is considered highly polluted and treatment is required before release

3.3.2 Practice

The first treatment facilities in Germany were implemented in the 1960's and aimed to protect groundwater protection areas or to provide flood prevention. The number of central treatment facilities for road runoff in Germany is estimated as above 1 000. The most common centralised treatment facilities are sedimentation/retention basins, followed by soil filter infiltration facilities. Sedimentation basins mostly consist of a concrete basin for removal of coarse sediments combined with an oil separation wall, Figure 3.5.

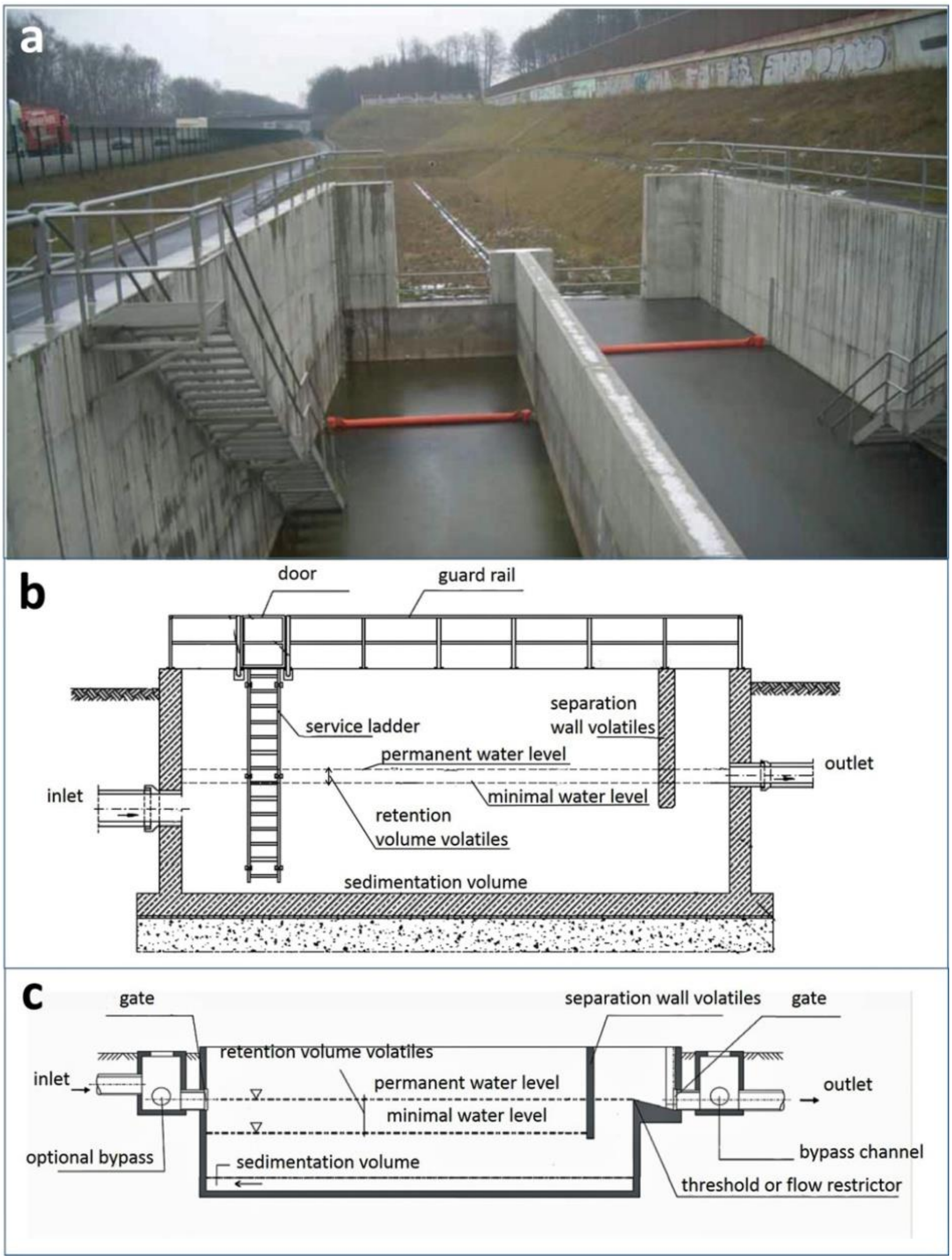


Figure 3.5. *Centralised treatment facilities in Germany. Sedimentation basin for pretreatment and oil separation (a) schematic (b), and complete treatment in a settling basin with oil retention (c). Sources: Birgit Kocher, BASt (a), DEGER (b) and FGSV (c).*

Most of Germany's recent treatment facilities are a combination of sedimentation basins and soil infiltration filter basin, Figure 3.6. Typical soil filters are constructed from several layers of medium and coarse sand combined with filter material, Figure 3.7. They are typically designed to drain a hydraulic load of 1-2 meters in 24 hours. Drying up between rain events is necessary to maintain the soil filter's functionality over time. In general, the water that percolates through the soil filter is of high quality.

Figure 3.6. *Examples of German treatment facilities for highway runoff, showing soil filters as treatment step that follows initial sedimentation and oil separation. Source: Second Bremer Soil Filter-Workshop 26.08.2009, Karl Diefenthal, Landesbetrieb Straßenbau NRW, Regionalniederlassung Rhein-Berg, Außenstelle Köln.*

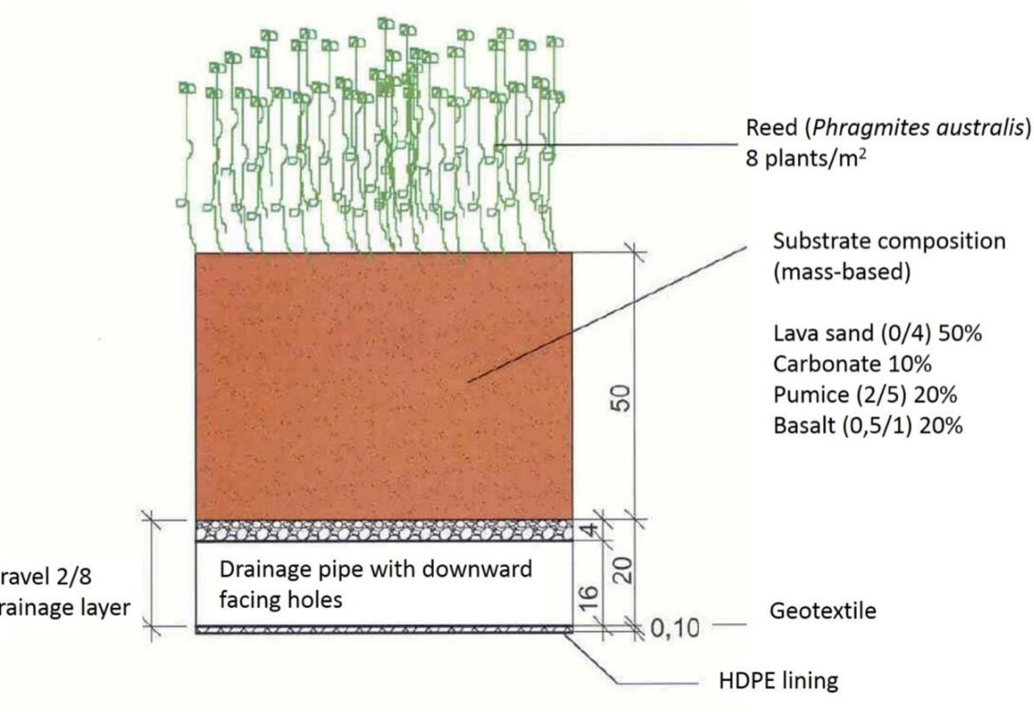


Figure 3.7 *Typical cross-section of a German soil filter layer as in use since 2009. Adapted from Second Bremer Soil Filter-Workshop 26.08.2009, Karl Diefenthal, Landesbetrieb Straßenbau NRW, Regionalniederlassung Rhein-Berg, Außenstelle Köln.*

Table 3.5. German design criteria indicating when treatment facilities for road runoff are required.

Design criteria	Decision	Document
AFS_{63}	Requires treatment according to the expected annual load of suspended solids smaller than 63 µm	DWA-A 102/BWK-A 3 (Grundsätze zur Bewirtschaftung und Behandlung von Regenwetterabflüssen zur Einleitung in Oberflächengewässer, draft October 2016)
ADT (annual average daily traffic)	Pollutant load according to vehicles per day	(Richtlinien für die Anlage von Straßen – Entwässerung, RAS-EW, 2005)
Groundwater protection areas and susceptible ecosystems	Decision process to determine the required treatment	(Richtlinien für die Anlage von Straßen – Entwässerung, RAS-EW, 2005)

Requirements and design

The Road administration (Straßenbauamt) is the authority responsible for the decision to build treatment facilities. Factors that influence the decision-making process are legislative demands, current practice and recommendations by environmental- and construction consultancies. Environmental requirements are largely incorporated in federal legislation. Adaptations of treatment facilities can be made to accommodate local conditions, such as spatial restrictions or local environmental restrictions depending on the receiving waterbody. Although the principles for treatment are generally the same, each facility is unique.

The decision process tends to result in sensible choices for treatment facilities but exceptions, particularly over dimensioning, do occur. The treatment practices in place are in agreement with EU's environmental quality standards applicable to surface water. In most cases, infiltration by the road shoulder supplies sufficient purification to meet the given standards.

Factors that influence the layout of a treatment facility are: local hydrology, topography, geology, soil type, existing drainage systems, permits, risk analysis, traffic intensity, legislation, costs, environmental quality standards, water purification, retention, protection of surface- and groundwater.

Construction phase

Building contractors hired for the construction of road runoff treatment facilities generally possess sufficient hydraulic engineering competence to build well-functioning facilities. One recurring problem, however, is that deviations from construction drawings are not always documented when drawings are updated. Personnel responsible for the pre-commissioning inspection of treatment facilities generally have the required competence to evaluate functionality. There is, however, a decrease in capacity among staff, which was attributed to the increasing privatization of public services.

Handing over to the proprietor

Procedures for handing over treatment facilities to their proprietor before commissioning are not sufficiently systematic and standardised to guarantee that all relevant information is transferred and archived for future reference. Operation manuals and maintenance plans are transferred to a higher degree than other relevant information, such as construction drawings and preliminary investigations. Transferred documents are usually archived both electronically and in print. Archiving is increasingly centralised at the federal state level.

Operation and maintenance

Maintenance and service of treatment facilities and handling of accumulated sediments are considered in the legislator process and during the planning phase. The most widespread treatment of road runoff is local infiltration in the road shoulder and embankment. Typically, roads have stormwater collection ditches along the embankment. The largest part of the annual precipitation falls in the form of rain and road ditches are mostly dry at intensities lower than 15 l/s ha. Local infiltration is standard practice and is applied to more than 90 % of all roads outside of settlements. Rainwater that is not collected in stormwater systems or treatment facilities is not regarded as wastewater in Germany.

Collection and central treatment of road runoff becomes necessary in sensitive areas such as groundwater protection areas and susceptible ecosystems (as regulated in RiStWag, 2002, see above). The number of central treatment facilities for road runoff in Germany is unknown but estimated to well exceed 1000. The most common centralised treatment facilities are sedimentation/retention basins followed by a soil filter infiltration facility. Soil filters in combination with sedimentation/retention basins are prioritised treatment facilities and their number increase. The first treatment facilities were implemented in the 1960's and aimed to protect groundwater protection areas or provide flood prevention. Soil infiltration filters are constructed from several layers of medium course sand and a filter material. Soil and are designed to drain a hydraulic load of 1-2 meters in 24 hours. Drying up between rain events is necessary to maintain the filters functionality over time. In general, the water that leaves the soil filters is of high quality.

Constructed wetlands for road runoff retention and purification are on the decline in Germany as a result of more time-consuming and expensive maintenance measures in comparison to other technical solutions. A further complicating factor mentioned here is the possible establishment of populations of endangered flora or fauna in wetlands that aggravate or even prohibit maintenance measures. Underground stormwater retention facilities are considered undesirable due to difficulty in controlling its functionality.

Operational experience as a basis for future layout

Whether or not those with operational experience are given the opportunity to provide input during the early phases of construction and development of future treatment facilities varies between federal states and seems to depend mostly on the people who is involved in the project.

Functionality

Overall, the only functional control of a facility is focusses on hydraulic integrity. This is conducted shortly before commissioning the facility. Pollutant removal rates are not controlled by default. There are only few facilities where the function is followed up by effluent water sampling. These samples are, however, not taken with a flow dependent sampling design and thus difficult to interpret. Quality control of accumulated sediment, in order to estimate removal rates, is more common and considered more meaningful. However, this control has not yet been evaluated fully to standard practice.

Facilities originally built to prevent spills to surface waters after accidents involving dangerous goods, tend to function appropriately. These facilities uphold this function during a long period of time. Facilities are remediated and renovated after each accidental spill.

Control and supervision

Regular visual inspections of centralised treatment facilities are conducted by federal (local) road and highway maintenance agency (Strassen- und Autobahnmeistereien). Personal has an assigned stretch of road while they are responsible for. These agencies are responsible for all issues regarding road maintenance such as snow ploughing, winter salting, vegetation clipping, waste collection, accident clean up, repairs and road runoff management. Inspection protocols are drafted and archived by the agency. Whether or not there are requirements from supervisory authorities to be taken into account with inspections depends on the particular water authorities involved and the federal state. A trend towards more regulations is observed, though.

There are at present no requirements to report annual inspection and maintenance protocols to the environmental authorities, though reporting to road administrations occurs in some cases. Frequency of inspections is not regulated, but the recommendations in H-KWES (FGSV, 2011) are in widespread use.

Damage by erosion and other minor malfunctions are generally fixed relatively swiftly. Clipping and trimming of vegetation on the road shoulder and embankment occurs regularly to guarantee good visibility for traffic. Soil filters and infiltration basins, however, are often "forgotten" when roadside vegetation is clipped. Control of sediment accumulation levels and sampling is often forgotten as well.

Ongoing maintenance

Most road and highway maintenance agencies follow the recommendations in H-KWES (FGSV, 2011) regarding frequency and parameters to be taken into account. Recurring problems with maintenance measures are: lack of personnel for adequate implementation, inadequate or incomprehensible stock records, and poor accessibility to the facility from the road.

Knowledge gaps

Future research should aim to optimize spatial requirements for facilities as well as batch operation. An important aim mentioned is the need to investigate if future facilities can be smaller and more cost-effective whilst maintaining high removal efficiency. The need to investigate if existing facilities are adequate for removing all suspended solids with a diameter smaller than 63 µm (AFS63) is also indicated.

Removal of accumulated sediments

Removal of accumulated sediments is thus not common. Sedimentation basins for example, tend to be designed in such a way that they can accumulate sediments for many decades. One example for dredging is given for a facility built 1965 during the interview. There are at present no recommendations for sediment removal practices but there is an ongoing research project at BASt that aims to formulate such recommendations. Road maintenance agencies have no separate budget for sediment removal, such measures must be financed from their overall budget. Fees for landfilling/deposition of the accumulated sediments are estimated to represent about 80% of total costs associated with dredging.

Most central treatment facilities in Germany have a forebay for sedimentation of coarser sediments such as large sand particles and gravel. Forebays are relatively easy to empty and the coarser fractions tend to carry smaller pollutant loads. Finer particles accumulate in the facilities main compartment over the course of decades. To remove these sediments the main compartment needs to be dredged, the resulting sludge subsequently drained before landfilling or incineration. In general, the fine sediments are unsuitable for use because of high pollutant loads of particularly heavy metals and mineral oil hydrocarbons.

Because the Waste Framework Directive (HP 14 ecotoxicity) is relatively difficult to interpret the decision whether or not fine sediments are classed as hazardous or non-hazardous waste in practice depends largely on the federal state involved. Most states base their decision on heavy metal or PAH concentrations as described in the "Requirements for the material recycling of mineral waste" (LAGA M20). The classification hazardous/non-hazardous mostly impacts the costs for final deposition/landfilling and not the cost for transportation.

Pollutant load is not sampled before dredging as a method to follow up an individual facility's pollutant removal efficiency. Adequate removal is achieved by making sure research forms the basis for new legislation.

So far there are no long-term trends detectable in pollutant loads in sediment, apart from a recent minor drop in lead concentrations, mainly attributed to a ban for lead wheel weights since 2002.

3.4 Austria

In Austria, typical facilities for central treatment of road runoff comprise two treatment steps. First, ditches and/or culverts collect the road runoff in a concrete sedimentation basin (first compartment). After a certain residence time in this compartment, runoff water reaches a second compartment through an oil separator and a distribution structure, Figure 3.8. The second compartment is a soil infiltration basin with alternating humus and gravel filter layers. The purified water is discharged to adjoining surface- or the groundwater after infiltration.

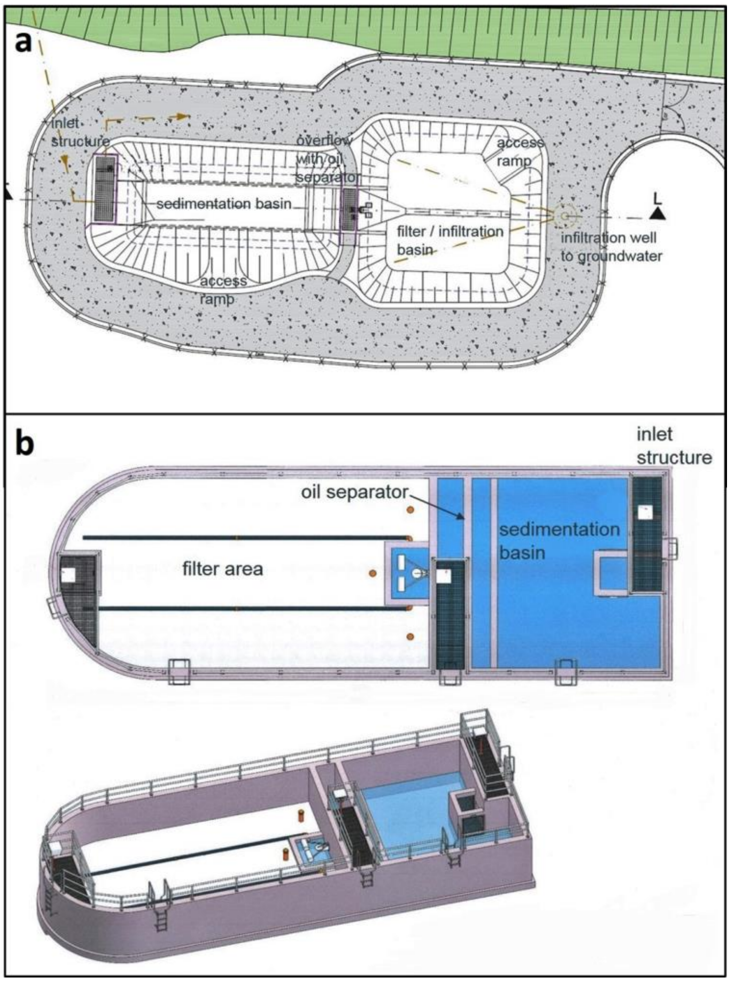


Figure 3.8. Two typical soil filter facilities (a and b) for treatment of road runoff in Austria. Source ASFINAG GmbH and SW Umwelttechnik.

3.4.1 Legislation

The OEWAV regulation, Regelblatt 25, stipulates the guidelines and technical instructions for planers (OEWAV, 2002). The guideline suggests that runoff water originating from highways, defined as roads having an AADT higher than 15 000 vehicles per day, should be collected separately and, if possible, purified before discharged into rivers. The minimum requirements for purification are a mechanical (sedimentation based) treatment and filtration. If the relation of the impermeable surface area of the road (As) to the average river discharge of the receiving waterbody is higher than 0.1, it is stormwater may not be discharged until proof is provided that water quality downstream will not be negatively impacted.

When impaired water quality downstream cannot be ruled out a common treatment measure is to infiltrate the water in a soil filter basin, following mechanical pre-treatment. The soil of the infiltration basin requires a minimum hydraulic conductivity of 10^{-5} m/s (36 mm/h).

3.4.2 Practice

Treatment of road runoff has been in practice for approximately 30 years, when it became regulated by law. At present ASFINAG operates more than 3000 treatment facilities across the country. The facilities covered under the scope of the interview are all centralised facilities for collected road runoff. Soil filters with a 30 cm filter layer represent the most common form of treatment in Austria today.

Operational experience as a basis for future layout

People responsible for maintenance of treatment facilities are not regularly involved during the early phases of construction and development, although exceptions do occur. The interviewee perceives that there is room for improvement when it comes to benefitting from operational experience during the planning phase.

Handing over to the proprietor

The need to improve the transfer of information material and subsequent training/schooling of operators is indicated during the interview, historically this has often not been the case. Transferred document are archived both electronically and in print on location of the facilities.

Functionality

Regular sampling of the inlet and outlet, as well as studies on the load and condition of the soil filter, are mandated by the authorities. Following certain rain events basin size is controlled in order to ascertain it´s that retention capacity is adequate. Water volumes that exceed the retention capacity bypass the facility via an emergency spillway. Hydraulic functionality is controlled by checking if the facilities drain sufficiently quickly after large rain events. Completed drainage to dry state should occur within 48 hours to prevent clogging of the soil filter. In practice, diminished hydraulic functionality (clogging of filter and culverts) does occur frequently. Problems can often be attributed to water from other sources than roads (e.g. runoff from other areas, drainage water and groundwater) entering the facility.

Pollutant removal efficiency is followed up by sampling of effluent water and soil sampling of the filter layers. Analysis results are reported to the authorities for follow up and control.

Spill containment in case of accidents, involving hazardous substance, functions as planned in most facilities. Levers and gates that can be operated by accident crews ascertain that hazardous substances are retained in the facility for subsequent clean-up. If the entire spill is contained in the oil separation compartment, clean-up is relatively easy. If the spill reaches the soil filter, the filter material is excavated and replaced.

Control and supervision

There are no electronic control systems in use today. Regular on-site inspections are conducted by maintenance personnel. Just as in Germany ongoing maintenance is delegated to local highway maintenance agencies (Autobahnmeistereien) that are responsible for between 10 and 100 treatment facilities. Required maintenance measures are usually described in the operating manual of the treatment facility. Maintenance protocols are archived either by the highway maintenance agency or by ASFINAG. Controlling authorities only get involved when certain parameters are exceeded or when construction or maintenance deficiencies are identified. Inspection intervals vary from quarterly to once every five years and are determined by requirements set by the local authorities. The interviewee even states that there are a number of facilities that are never inspected.

Functional deficiencies identified by the authorities are always fixed promptly. ASFINAG conducts additional corrective measures when deemed necessary. The most common recurring problems are clogging of soil filters due to too infrequent clipping of vegetation or sediment build-up.

Operation and maintenance

Regularly conducted maintenance measures include clearing of debris from in- and outlet structures, vegetation clipping, removal of accumulated sediments, minor repairs to levers and gates and repair of erosion damage.

Maintenance tasks are identified, ordered and conducted during periodic inspections by ASFINAG operators. Inspection consist of a visual control for erosion damage to the embankment, concrete structures and road surface. Replacement of soil filters and other repairs are carried out as directed by the authorities. Obvious flaws are fixed by ASFINAG independently. Depending on the scale of the necessary measures they are either carried out by ASFINAG's own crews or by building contractors. Recurring problems associated with maintenance are lack of time or personnel, insufficient understanding of what needs to be done and poor planning for maintenance during the design phase of facilities.

Knowledge gaps

The interview participant indicates the need to develop low-maintenance and longer-functioning facilities for road runoff treatment. Special focus should be on minimizing the ageing process during operating conditions. The living soil filter system should in the future be abandoned in favour of more controllable technical solutions.

Removal of accumulated sediments

Sedimentation basins are dredged as soon as approximately 1/3 of maximum capacity has accumulated. Dredged sediments are drained and can thereafter be deposited/landfilled. After about 10 years of operation, soil-filter layers are excavated and replaced.

3.5 Switzerland

In Switzerland, road runoff is handled differently, depending on soil type, hydrogeological situation, ADT and runoff flow rates. Requirements for treatment are also depending on the degree of water contamination, se Figure 3.9. Where the route and the soil feature allow infiltration in the road embankment it is the preferred solution from environmental, planning, and economical perspective (Trocmé Maillard et al. 2013). When this solution is not possible, appropriate road runoff treatment plants are built for the collection and retention of contaminated road runoff. These plants, built outside the road line are often in conflict with other interests, such as land ownership etc. Sustainable solutions, which enable a robust operation and ensure appropriate performance are favoured. Space-saving solutions that remain energy-efficient are preferred.

Based on existing projects, a cost-benefit comparison tool has been developed. This tool is used to assess different solutions efficiency and economic costs. It also takes into account the impact on land use and environment aspects.

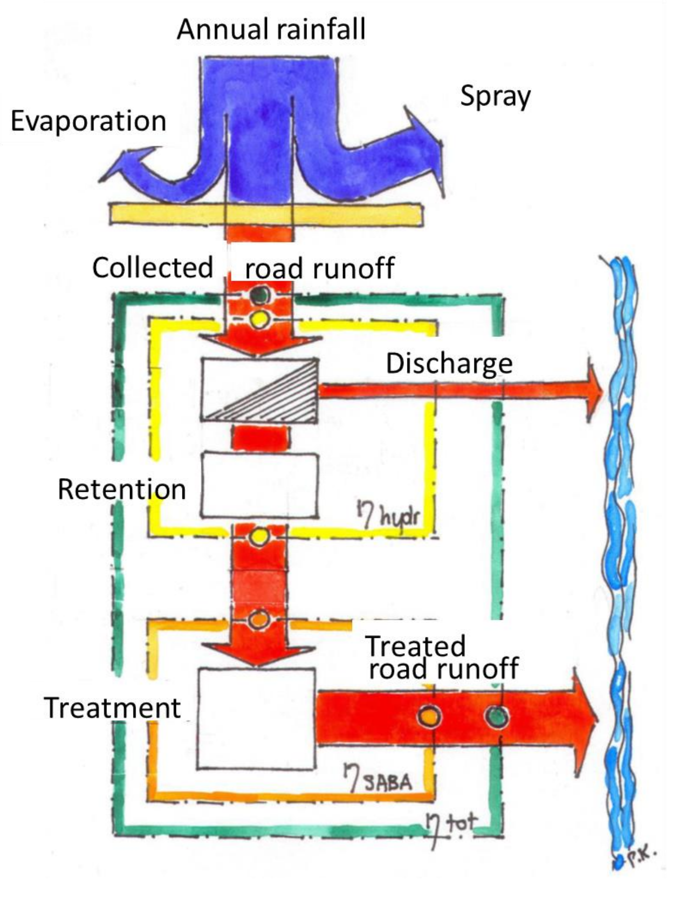


Figure 3.9. Description of the drainage system with definition of the efficiency (Trocmé Maillard et al. 2013).

3.5.1 Legislation

Permitting procedures follow the national Road law. Permitting procedures include rebuilding of a national road (construction), structural modification of an existing national road (expansion), and maintenance practices (Trocmé Maillard et al. 2013).

Responsibilities for construction and expansion:

- National road projects are approved by the Federal Council.
- The project documents are governed by the Swiss Confederations "National Road Ordinance".
- National road projects have to be approved by the Federal Department of the Environment (DETEC). As the leading authority DETEC grants all permits required under federal law. The documents necessary for these permits are available in the project dossier. The cantonal environmental protection and water protection departments advise the decision-making authorities. The Federal Office for the Environment (FOEN) assesses the environmental compatibility of the national road project. The Cantons have to be involved early in the process. The Federal Road Office (ASTRA) prepares the necessary documentation and contacts the related cantonal authorities.
- DETEC generally delegates the implementation of the requirements and their control ASTRA.

Detailed projects of the national road are approved by ASTRA.

Maintenance projects are approved in accordance ASTRA. In fulfilling this task, ASTRA is also responsible for the implementation of the Environmental Protection Act and the Water Protection Act.

Maintenance of national roads is carried out in accordance with a Maintenance Planning document. This planning is used for long-term preservation of the structure of the national roads. Conservation projects usually include expansion and maintenance. The approval procedures are based on the above.

3.5.2 Practice

The Swiss Federal Office for the Environment (DETEC) recommends infiltrating the road water into the embankment if the soil is formed of A and B horizons with 10–30% clay content (Boivin 2008). Such materials are, however, not always available in some parts of Switzerland, where soils have A/C profile with sandy-loam texture instead.

Control and supervision

The requirements for Saba are based on an annual water quantity and the quantity of pollutants. The requirements on the owners of the treatment facility is that the plant is maintained in a working condition (Trocmé et al. 2013). For this purpose, regular controls are required. Depending on the objectives, the controls must include information on:

- Acceptance levels;
- Function monitoring;
- Functional testing;
- Performance testing of new procedures.

4 Analysis and discussion

4.1 Interviews

The interviews conducted with authorities in Sweden, Norway, Germany and Austria touched upon legislation and practice within stormwater treatment and maintenance.

In Sweden, the Swedish Environmental Law (Miljöbalken) and the EU Water Framework Directive (WFD) regulate stormwater management. The Weser judgment (European Court of Justice, C-461/13 2015)) is also highly relevant, since it strictly prohibits negative impacts on water quality by all new development (se chapter 3.1).

Despite the requirements from the legislation above, stormwater and discharge quality are not monitored on a regular basis. In both Sweden and in Norway, the decision whether or not to restore a pond is generally solely based upon basic visual inspections of sediment accumulation.

In Sweden, local environmental authorities often require the construction of ponds as an environmental measure. The design of ponds and underground retention basins in Sweden and Norway varies depending on local constructors. In both countries, the most common treatment facilities for stormwater are sedimentation ponds. Around 800 ponds have been constructed in Sweden since the early 1990’s (according to STA). The first Norwegian ponds were constructed in the early 2000’s. In both countries, the environmental authorities were involved in the decision to plan and construct these.

Results from interviews in Sweden indicate that the operation and maintenance of treatment facilities is largely neglected. Emptying and restoration of ponds is not frequently performed, largely due to lack of accessibility. Access roads and areas assigned for treatment of excavated sediment are often lacking or not suitably prepared for heavy machinery. Lack of accessibility and maintenance can result in poor water treatment and even in the malfunction of the stormwater treatment system. In addition, there are uncertainties regarding performance and functionality of the ponds. In Sweden, ponds are often designed with only one section, and thus coarse sediment is not separated before entering the pond, while in Norway, forebays are built to separate coarse sediment from fines. In both countries sediment is excavated under water saturated conditions.

The key message, resulting from the interviews in Sweden and Norway, is that ponds should be designed so that they are easy to build, maintain and restore. It is also an advantage if the facilities have a similar design, to facilitate working efficiency of the maintenance staff. Reliable cost analyses relating to construction, operation and maintenance are sparse.

Stormwater treatment in Germany differs substantially from that in Sweden and Norway. The total number of central treatment facilities for road runoff in Germany is estimated to exceed 1000 facilities. Course sediments and oil fractions are systematically separated and road shoulders and embankments are often used as infiltration zones. The design criteria for treatment are based on ADT and on an assessment of the expected annual load of suspended solids smaller than 63 µm (AFS63). Treatment requirements, described in the documents RiStWag and RAS-EW, are based on risk assessments of accidents with hazardous substance discharge as well as diffuse pollution. (See section 3.3. and Tables 3.3 and 3.4 for details).

A new version of RAS-EW is currently being developed and is expected to be published 2019. The importance of infiltration was high-lighted, even under conditions where only a part of the road runoff volume can be infiltrated.

The most common centralised treatment facility in Germany consists of a concrete basin for removal of coarse sediments, including an oil separation wall, in combination with soil infiltration filters. These filters contain several layers of filter material consisting of medium to coarse sand, and are designed to drain the hydraulic load within 24 hours. Experience of these constructions shows that coarse sediment, accumulated in the forebay, constitutes a major part of the total sediment. This fraction is easily drained and its contaminant level is usually low, thus enabling relatively easy collection and drainage when the concrete basin is emptied. Oil spills are dealt with before they contaminate large areas and huge volumes of soil and water. The infiltration filters function as both filter and buffer, and can accumulate dissolved substances and thereby protect the groundwater or surface water. Metal and organic pollutants will predominantly bind to particles and usually have low solubility at pH values around 6.5 to 8. Other processes during infiltration and percolation are building a "filter cake“, which itself contributes to sorption of pollutants. This sorption contributes more to the pollutant retardation than the underlying 30 cm medium sand filter. The sand has a buffering stock to stabilize pH. Sedimentation is assessed to be around 1 cm / year.

All interviewees pointed out that the use of road salt to increase traffic safety raises some questions of how to minimize its detrimental effect on the aquatic environment.

4.2 Suspended solids versus pollution transport

Stormwater contamination is caused by dissolved contaminants and contaminants adsorbed to suspended particles in the water. Generally, the degree of contamination increases with decreasing particle size and increasing organic content. Metals such as Zn, Cu and Ni appear in stormwater mainly in the fines. The same pattern is valid for organic contaminants like PAHs.

Particle size and organic content are of interest as these are adsorbents and can be a source of suspended particles in stormwater. Sedimentation is one major treatment solution, especially well functioning for coarse particles. Sedimentation efficiency decreases with decreasing particle size. By dry mass the coarse fraction contains the major part of the total sediment, while fines represent only a small fraction. The coarse fraction is easily dewatered and generally has a low degree of contamination. Pollution is associated to colloids and dissolved contaminants. Sediment with high organic content also has high water content. Separate sedimentation of coarse and fine particles can accumulate contaminants in a smaller fraction of the sediment.

Infiltration can decrease the number of suspended particles and the amount dissolved in the discharged stormwater after treatment, Table 4.1.

Table 4.1. Contribution of different treatment solutions for minimizing pollution transport.

	Coarse particles	Fines	Colloids	Dissolved
Forebay	Accumulation	No accumulation	No accumulation	No accumulation
Pond	Mixed accumulation		No accumulation	No accumulation
Infiltration	-	-	Accumulation	Some accumulation

4.3 Comparison of the preferred solutions in Sweden, Norway and Germany

As mentioned Sweden, Norway, Germany, Austria and Switzerland use different treatment solutions for road runoff, see Table 4.2, and different design criteria. Low-cost systems are generally preferred. Ideally, when cost is estimated it should include the total cost of construction, maintenance and restoration. The treatment solutions environmental efficiency is also a subject, which should be addressed. However, the environmental consequences related to different treatment solutions are poorly described in general, and are believed to have a large site-specific variation.

Table 4.2. Preferred stormwater treatment solutions by country.

	Sweden	Norway	Germany	Austria	Switzerland
Road shoulder	X		X	X	X
Forebay	(X)	X	X	X	(X)
Pond	X	X			(X)
Infiltration basin			X	X	(X)
Filter solutions (Technical solutions)					(X)

In Sweden ponds are used as stormwater treatment facilities. Catchment area, runoff volume, pond area or volume and in some cases ADT is the design criteria for building a pond. When planning municipal ponds, mainly catchment area and pond area are used as design criteria.

After sufficient sedimentation in the pond, the water reaches the surface waterbody. Coarse and fine particles are mixed in the pond, with some separation of coarse particles accumulating near the inlet and fines near the outlet. The submerged outlet also functions as an oil separator. The sediment will have low DS, high TOC, and low water retention capacity and can accumulate road specific pollution present in the stormwater. The life span of a pond is limited. The discharged water will leak fines (colloids) and dissolved pollution,

Figure 4.1. Dredging and handling of water saturated organic sediment is expensive, as the dredged sediment has to be de-watered before it is landfilled.

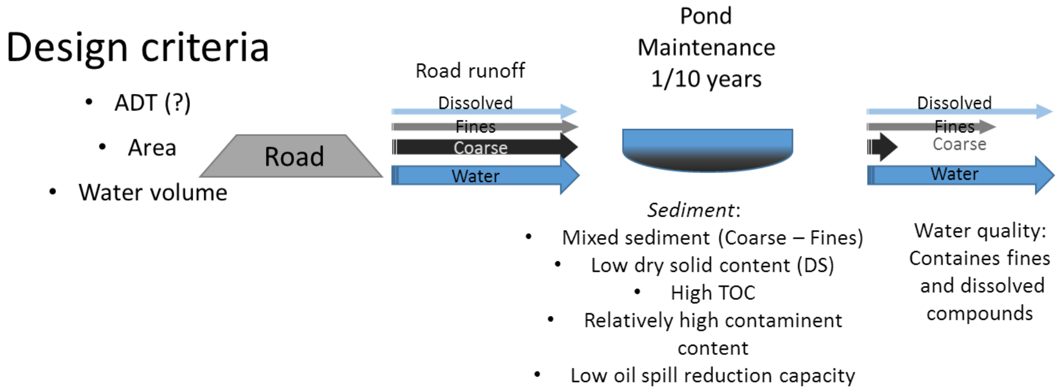


Figure 4.1. Conceptualised description of the main treatment of road runoffs in Sweden.

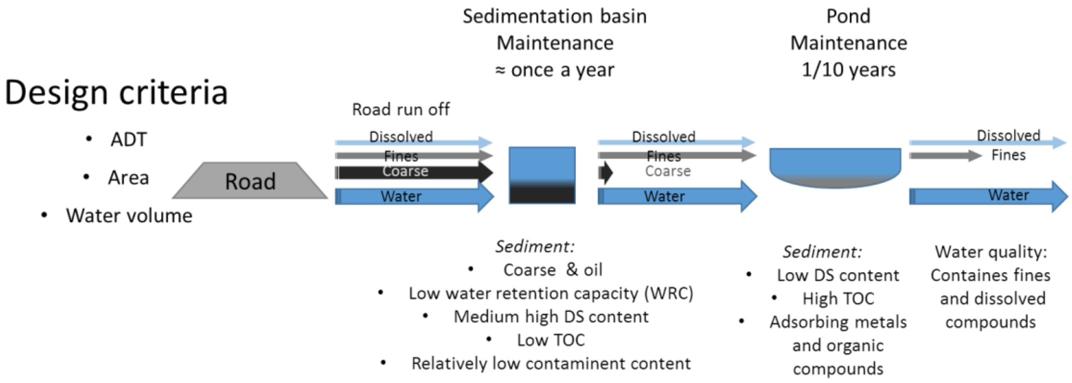


Figure 4.2. Conceptualised description of the main treatment of road runoffs in Norway.

In Norway, the standard design of a sedimentation pond includes a smaller pre-sedimentation magazine (forebay) and a main pond (Figure 4.2). Catchment area, runoff volume and in some cases ADT are the design criteria for building a pond. The inlet and the outlet are under a permanent water surface to ensure the facilities function during wintertime and function as an oil separator. Coarse particles with low contaminant content and low water retention capacity will sediment in the forebay, which is emptied each year. The forebay accumulates most of the particle in the stormwater, limiting the accumulation to fines within the main pond. This leads to slower accumulation rates and longer life span before the pond needs restoration (dredging). The sediment tends to have low DS, high TOC, and high-water retention capacity. Pollutants are also likely to accumulate in the fines. The estimated life span is longer than that of ponds without pre-sedimentation basins. The outflow will, however, leak fines (colloids) and dissolved pollution. The facility accumulates coarse and fine particles separately. Coarse sediment is easily de-watered and contains only low levels of pollution, and therefore can be regarded as a low contamination risk. Coarse material can be used as construction material on landfills, eliminating landfilling costs. The dredged fines from the pond are saturated with water, have high organic content and high-water retention capacity. This kind of sediment is expensive to de-water and landfill.

Landfilling costs are high, due to high water content; however, the volume is limited as the coarse fraction is handled separately.

Germany (and Austria) utilizes pre-sedimentation basins/tanks (forebay) together with infiltration, see Figure 4.3. Catchment area, runoff volume, ADT and particle load (suspended solids) of the road runoff are used as design criteria when building a pond. The benefit of combining ponds/basins with infiltration facilities is that particle associated pollutants are treated by sedimentation and soluble pollutants by an infiltration and sorption processes. The forebay accumulates most of the particles in the stormwater, limiting the accumulation to fines in the infiltration basin. This leads to slower accumulation rate and longer life span of the infiltration basin. The sediment in the forebay will have medium high DS, low TOC, and low water retardation capacity. It is likely that pollution will accumulate in the fines as water is infiltrating though a humus layer and medium sand layer before entering the receiving ground or surface water. The estimated life span of the infiltration basin is approximately 20 years or more. This facility accumulates coarse and fine particles separately. Coarse sediment is easily de-watered and poses a low risk of contamination. Coarse material has low landfilling costs. The excavated fines from the infiltration basin are not saturated with water, reducing the need for de-watering as well as associated landfill costs.

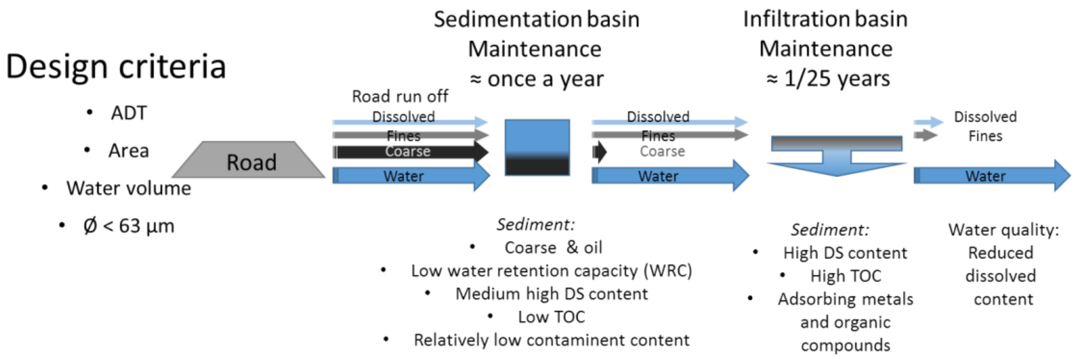


Figure 4.3. Conceptualised description of the main treatment of road runoffs in Germany.

4.4 Cost efficiency

This section discusses short and long-term cost and environmental benefits of using the three different types of designs to improve water quality: 1) stormwater ponds, generally used by the Swedish road administration, 2) stormwater ponds with a forebay, used by the Norwegian road administration, and 3) soil filtration basins with a detention tank, generally used by German and Austrian road administrations.

When comparing these three alternatives, it is apparent that the pond-only solution is less maintenance intensive. However, sedimentation is highly dependent on the size of the catchment area and its properties, pond size, water velocity etc., and thus effective sedimentation is difficult to ensure. In practice, the dredging interval for pond sediments is approximately seven to fifteen years. Visual inspection to control for extensive vegetation and blockage of in- and outflow is relatively easy to perform, however, sediment accumulation in the pond and how it effects sedimentation and flow retention is, however, generally not controlled. From several hundred ponds built in the last 25 years, only a few have been dredged or emptied of sediment. Ponds with sedimentation bays or magazines are, by design, more maintenance intensive. This is due to greater sedimentation within a smaller volume. The maintenance interval for a forebay is once every year to once in three years. This leads to a lower sedimentation load of the actual pond. Ponds are emptied after ten years; however, sediment volumes are lower than for the pond-only option. Maintenance requirements are similar in both solutions. The third solution consisting of a sedimentation magazine and a soil infiltration is maintenance intensive. Dysfunctional infiltration due to clogging is easily detectable as it is visible that it causes malfunction, i.e. failure to infiltrate.

In general, the efficiency of water quality treatment is improved by the incorporation of upstream multiple pre-treatment barriers, e.g. by using filter strips, swales or forebays. Pre-treatment reduces the influx of large sediment loads and improves surface infiltration capacity. A fore-bay allows coarser sediments to settle out of suspension before the runoff enters the main treatment facility, and concentrates sediment accumulation in a small easily controlled area. The forebay can be prepared for easy access and removal of the accumulated sediment, thereby reducing costs for sediment removal.

Pre-treatment is especially important for soil filters. The performance of infiltration or soil filter systems depend on the properties of the soil or the soil filter construction. Heavy sediment build-up leads to reduced infiltration. Accumulated fines (silt and organic material) have low inherent water content and are generally dry when removed. This sediment is easily handled and when not contaminated can be easily reused or recycled.

Sediment in ponds, especially without pre-treatment facilities, are often wet (have low dry solid content) and need to be de-watered and landfilled. Without a forebay, sediment build-up is uncontrolled and difficult to monitor. Often, sediment removal from the whole pond is required with increasing risk of potential damage to the receiving water.

Costs include the following:

- Design, planning and contingency costs
- Operation and maintenance costs
- Disposal costs
- Environmental costs

Costs for design and planning include recommendations that meet management goals or objectives. In an environmentally sensitive area, design and planning costs may increase. The objectives of the design are to provide drainage water management based on hydraulics and water quality. In general, design and planning cost are around 30 % of the construction costs, Woods-Ballard et al. (2014).

4.4.1 The Nacka case

To give a more detailed account of costs involved two cases are presented, where two ponds were emptied during 2015 – 2016 in Nacka municipality. These ponds differ in size and sediment volumes. The smaller (Myrsjön- Case 1) was a pond with 250 m² pond area while the bigger (Långsjön-Case 2) had a pond area of 2800 m². In both cases a suction pump was used to empty the accumulated sediment. The sediment was then dewatered in a geotextile tube. Thereafter the dewatered sediment was landfilled. Background data for the two ponds are presented in Table 4.3.

Table 4.3 Background information on pond size, volume sediment handled and total cost. Sediment was emptied by suction dredging and dewatered in geotextile tubes.

Actual size, volume and cost					Calculated cost		
	Pond size, m²	Volume dredged sediment, m³	Landfilled de-watered sediment, ton	Construction cost, €	Construction cost/pond size, €/m²	Construction cost/dredged sediment, €/m³	Construction cost/de-watered sediment €/ton
Case 1	250	156	13	18 630	75	119	1 433
Case 2	2 800	2 100	330	243 000	87	116	736

Table 4.4 Calculated establishing, dredging, dewatering and landfilling cost.

	Case1 (Size 250m²)	**Case 2 (size 2800 m²**
Establishing charge, €	5300	5700
Dredging, 45 - 60 €/m²	11 250	168 000
De-watering, 90 - 100 €/ton de-watered sediment	1170	33 000
Landfilling & Transport costs, 70 - 110 €/ ton	910	36 300
Sum of construction cost, €	18 630	243 000
Construction cost/pond size, €/m²	75	87
Construction cost/dredged sediment, €/m³	119	116
Construction cost/de-watered sediment €/ton	1 433	736

Generally suction dredging increases the volume of sediment tenfold. Dewatering is necessary to reduce the amount of water present. The method used in these cases was filtering the slurry through geotextile tubes. As shown in Table 4.5, 156 m³ sediment slurry (around 156 tonnes) was dewatered to 13 tonnes (Myrsjön) and 2 100 m³ slurry (around 2 100 tonnes) was reduced to 330 tonnes.

Small pond size gives a high rehabilitation cost per ton sediment. The cost of managing one tonne of sediment at Myrsjön, (200 m² pond) was 1 433 €, while at Långsjön the sediment management cost per tonne was 736 €. In both cases around 60 - 70 % of the cost was related to suction dredging. Dewatering cost will depend on the dredged sediments water content as well as the fine and organic fraction of the sediment. Dewatering efficiency decreases with increasing fine and/or organic content. Though, only 3 – 7 % of the total cost were directly related to landfilling and transport, se Figure 4.4.

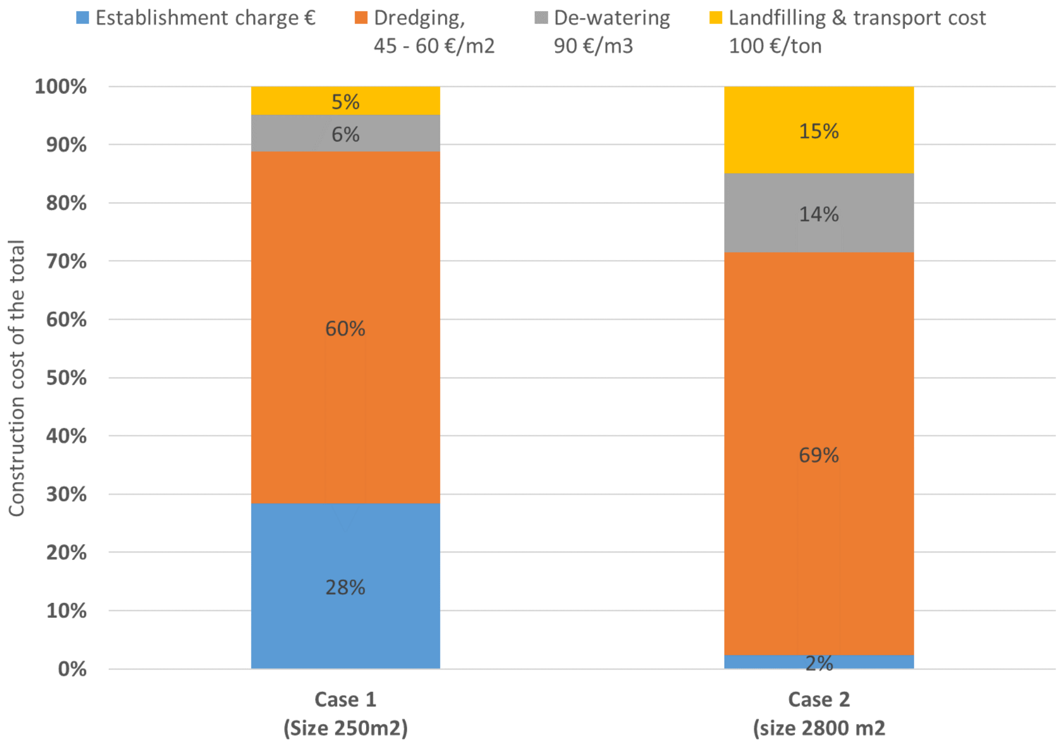


Figure 4.4 *Total cost and how it is composed depending on size of the pond, calculation based on data from Myrsjön and Långsjön.*

4.4.2 Cost comparison of different solutions

In this section, maintenance and rehabilitation costs are compared for three solutions: 1) pond, 2) forebay combined with a pond, and 3) forebay combined with a soil filter. For these examples, the catchment area is 10 000 m² and the size of the treatment facility is 2 % of the impervious catchment area. For solutions 2 and 3, the pond area is divided and 90 m² is assumed to be used as forebay and 110 m² as pond or soil filter, respectively (Table 4.5).

Table 4.5 Area needed for different treatment facility types.

	Pond	Forebay + Pond		Forebay + soil filter	
		Forebay	Pond	Forebay	Soil filter
Catchment area (A^C)	10 000 m^2	10 000 m^2		10 000 m^2	
Treatment Facility (A^T)	200 m^2	(6x15 m^2) = 90 m^2	110 m^2	(6x15 m^2) = 90 m^2	110 m^2
Ratio (A^T/A^C)	2%	2%		2%	

The presumed sediment load is 1000 kg/ha and year, which includes sand, silt and clay particles. It is assumed that 30 % of the particles are < 63 µm, hence, this road section requires a treatment facility according to German regulations on sediment for particles < 63 µm (DWA-A 102/BWK-A 3, 2016). The accumulated sediment during a decade is 10 tonnes (DS) independent of the treatment facility.

4.4.3 Pond

The assumed accumulation of mixed sediment in the pond over a decade is 30 tonnes with a dry solid content of 33 %. A bulk density around 1,27 tonnes/m^3 will result in an in situ sediment volume of approximately 24 m^3. There are two alternative ways of handling this sediment, suction dredging or excavation. Both alternatives require a platform for handling the dredged or excavated sediment. Vegetation and organic content will complicate both dewatering and landfilling, since landfilling is not an option for sediment with an organic content above 10 % of DS.

Suction dredging – dry solid content decreases from 33 % to approximately 15 % as the water content increases during suction dredging. As a result, the amount of sediment increases to 67 tonnes and therefore dewatering before landfilling or re-use is mandatory. On-site or off-site dewatering alternatives are possible. On-site dewatering with geotextile tubes can increase the DS-content to 60 % depending on sediment quality, polymer added and time to settle. The amount of sediment after dewatering will be around 17 tonnes (Table 6.7).

Excavation – Before excavation, runoff water is by-passed and the pond can dry. The sediment DS content does not change and is about 33 %. This means that the total sediment amount is around 30 tonnes.

Rehabilitation costs depend on the size of the pond, the dry solid content of the sediment and the amounts of water handled together with the sediment. Based on the assumption that the accumulated sediment in the pond is emptied after 10 years, dredging and landfilling, without dewatering, will cost around 26 000 € (Table 4.4). Dewatering on-site reduces this cost to around 20 500 € due to lower handling and transport costs. Excavation of dry sediment, where excess pond water is drained, reduces costs to around 14 000 € (Table 4.4).

Table 4.4 Rehabilitation costs per decade for three alternative treatment solutions for a pond.

1) Rehabilitation costs/decade when the pond sediment is emptied (suction dredging) and sediment is dewatered *off-site* before landfilled.				
	Amount	Unit	Cost	Total Cost
Establishing*,&				5 000 €
Suction dredging &	200	m^2	55 €/m^2	11 000 €
Landfilling incl. dewatering (DS=15%) &	67	tonnes	150 €/tonne	10 000 €
Total (dredging/landfilling)				**26 000 €**

2) Rehabilitation costs/decade when the pond sediment is emptied (suction dredging) and dewatered *on-site* before transported to a landfill.				
	Amount	Unit	Cost &	Total Cost
Establishing				5 000 €
Suction dredging	200	m^2	55 €/m^2	11 000 €
Dewatering (geotextile tubes á 20 tonnes)	67	tonne	55 €/tonne	3 667 €
Landfilling (DS 60%)	17	tonne	50 €/tonne	833 €
Total (dredging/dewatering/landfilling)				**20 500 €**

3) Rehabilitation costs/decade when the pond sediment is excavated (dry sediment) and transported to a landfill. Cost for establishment is included in the excavation cost.				
	Amount	Unit	Cost &	Total Cost
Excavation (dry)*	200	m^2	55 €/m^2	11 000 €
Landfilling (DS 33%)	30	tonne	100 €/tonne	3 000 €
Total (excavation/landfilling)				**14 000 €**

* Establishing included

& Cost reference, Nacka-case

4.4.4 Forebay (Basin) and pond

Assuming that 70 % of particles settle in the forebay (coarse) and 30 % in the pond (fines), the forebay and pond will accumulate sediment with a dry solid content of 40 % and 33 % respectively. The accumulation of sediment in the forebay is approximately 17,5 tonnes per decade. The in-situ sediment's bulk density is 1,35 ton/m^3 will result in an in situ sediment volume of approximately 13 m^3. Common practice is to empty the forebay basin every year to ensure function. During a decade, the pond will accumulate 9 tonnes of sediment. Due to the size of the pond emptying is assumed to be needed once every decade. The sediment is emptied by suction dredging.

Suction dredging of the forebay – dry solid content decreases from 40 % to approximately 15 % as the water content increases during suction dredging. As a result, the amount of sediment increases to 47 tonnes. Dewatering with Geotextile tubes increases the DS-content to 60 % depending on sediment quality, polymer added and time to settle. The amount of sediment after dewatering will be around 12 tonnes (Table 4.5).

Suction dredging of the pond – dry solid content decreases from 33 % to approximately 15 % as the water content increases during suction dredging. As a result, the amount of sediment increases to 20 tonnes. Dewatering with Geotextile tubes increases the DS-content to 60 % depending on sediment quality, polymer added and time to settle. The amount of sediment after dewatering will be around 5 tonnes (Table 4.5).

Table 4.5 Rehabilitation costs/decade when forebay and pond sediment is emptied and landfilled.

a) Rehabilitation costs/decade when forebay sediment is emptied, dewatered and landfilled every year.				
		Unit	Cost &	Total Cost
Establishing				2 000 €
Suction dredging	90	m^2	55 €/m^2	4 950 €
Dewatering (geotextile tubes á 20 tonne)	47	tonne	55 €/tonne	2 567 €
Landfilling (DS=60%)	12	tonne	50 €/tonne	583 €
Forebay (dredging/dewatering/landfilling)				10 100 €

b) Rehabilitation costs/decade when pond sediment is emptied, dewatered and landfilled after two decades.				
		Unit	Cost &	Total Cost
Establishing				3 000 €
Suction dredging	110	m^2	55 €/m^2	6 050 €
Dewatering (geotextile tubes á 20 tonnes)	20	tonne	55 €/tonne	1 100 €
Landfilling (DS 60%)	5	tonne	50 €/tonne	250 €
Pond (dredging/dewatering/landfilling)				10 400 €
Total (Forebay and pond)				20 500 €

& Cost reference, Nacka-case

Dredging and landfilling of the dewatered forebay sediment cost around 10100 € during a decade. Excavating and landfilling the accumulated sediment in the soil filter needs no dewatering, and will cost around 1 455 €. However, excavation is only needed once per 30 years. The soil filter is then replaced with new sand and drainage layers.

4.4.6 Summary

The difference in the amount of sediment accumulated by the different facilities depends on the dry solid content (DS). Choosing suction dredging as method for emptying the treatment facility leads to increased water content and lower DS, which affects disposal options, since wet sediment needs to be dewatered before handling or landfilling. Table 4.7 shows that the amount and weight of dewatered dredged sediment, sent to landfill is the same in all cases. The main difference between the three different alternatives is how often the sediment requires removal, and the consequent rehabilitation work needed. As shown by the Nacka case, ca 90 % of the cost is related to work carried out by the contractor to establish and rehabilitate the treatment facility.

Table 4.7 Amount of sediment from the three different treatment facilities accumulated per decade.

		In situ sediment	Dredged wet sediment	Dewatered dredged sediment
Pond	Mixed sediment [tonne (DS)]	**30 (33%)**	**67 (15%)**	**17 (60%)**
Forebay + pond (Sum)	Sum [tonne]	**27**	**67**	**17**
- *Forebay (basin)*	*Coarse [tonne (DS)]*	*17.5 (40%)*	*47 (15%)*	*12 (60%)*
- *Pond*	*Fines [tonne (DS)]*	*9 (33%)*	*20 (15%)*	*5 (60%)*
Forebay + soil infiltration	Sum [tonne]	**23**	**47**	**17**
- *Forebay (basin)*	*Coarse [tonne (DS)]*	*17.5 (40%)*	*47 (15%)*	*12 (60%)*
- *Soil infiltration*	*Fines [tonne (DS)]*	*5 (60%)*	*NA*	*5 (60%)*

Based on the above the total cost for each treatment facility is summed up in Table 4.8. Planning design and building of the different facilities as well as operation costs are based on Woods-Ballard et al. (2014), and are roughly the same, as is the size of the different facilities.

The alternatives compared are the following:

- Pond, where suction dredged sediment is landfilled without dewatering on-site.
- Pond, where the sediment is dewatered after dredging (suction dredging) and then landfilled.
- Pond, with the possibility to excavate the sediment under dry conditions. The sediment is than landfilled.
- Forebay and pond, where the forebay is emptied each year and the pond is emptied after two decades. Sediment is landfilled after dewatering on-site.

- Forebay and soil filter, where the forebay is emptied each year and the soil filter rehabilitated after three decades. Forebay sediment is landfilled after dewatering on-site. Soil filter sediment is landfilled.

The sum of costs after a decade for each alternative is summarised in Table 4.8 and Figure 4.5. It is obvious that the treatment solution consisting of a forebay and pond has the lowest cost. This is mainly due to the ease of excavation, which is more cost efficient than suction dredging. The forebay solutions have about the same cost, as maintenance of the forebay is the same, and emptying the pond or soil filter is not necessary. This assumes that both types of facilities work well.

Table 4.8 Rehabilitation cost of the three different treatment facilities after a decade.

	Pond (landfill)	**Pond (Dewatering/landfill)**	**Pond Excavation, dry)**	**Forebay+Pond (Dewatering/landfill)**	**Forebay+soil filter (Dewatering/Landfill)**
Planning/design	2 100 €	2 100 €	2 100 €	2 100 €	2 100 €
Building	7 000 €	7 000 €	7 000 €	7 000 €	7 000 €
Operation/Maintenance	4 000 €	4 000 €	4 000 €	5 000 €	5 000 €
Rehabilitation - Forebay				10 100 €	10 100 €
Rehabilitation - pond	26 000 €	20 500 €	14 030 €		
Rehabilitation - soil filter#					Not needed
Total	**39 100 €**	**33 600 €**	**27 130 €**	**24 200 €**	**24 200 €**

Rehabilitation after three decades.

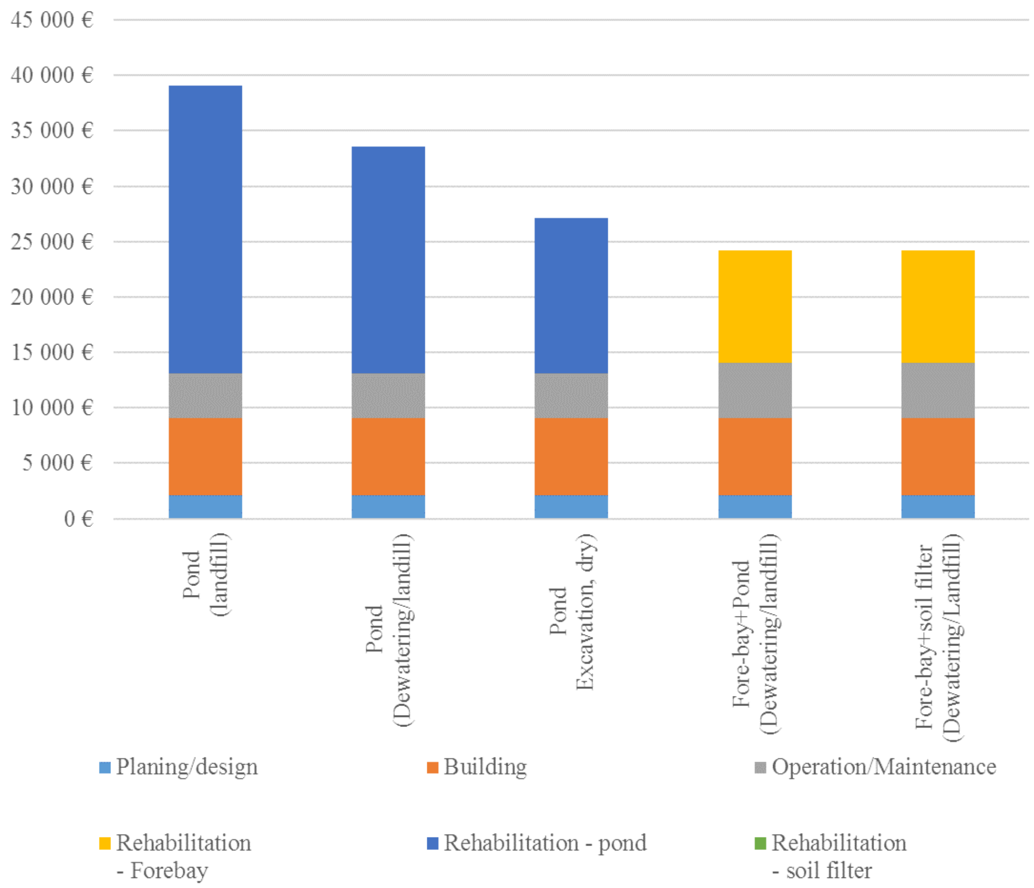


Figure 4.5 *Rehabilitation cost of three different treatment facilities after a decade, where the pond has been treated using different rehabilitation methods.*

The sum of costs after three decades for each alternative is summarised in Table 4.9 and Figure 4.6. The pond solution, where excavation of dry sediment is possible, and the soil filter solution has the lowest costs, followed by the forebay/pond solution. However, soil filter is not yet a proven solution under Nordic conditions, while ponds are well established as treatment solutions.

Table 4.9 Rehabilitation cost of three different treatment facilities after three decades.

	Pond (Landfill)	Pond (Dewatering/ Landfill)	Pond (Excavation, dry), landfill	Fore-bay+Pond (Dewatering/ Landfill)	Fore-bay+soil filter (Dewatering/ Landfill)
Planning/design	2 100 €	2 100 €	2 100 €	2 100 €	2 100 €
Building	7 000 €	7 000 €	7 000 €	7 000 €	7 000 €
Operation /Maintenance	12 000 €	12 000 €	12 000 €	15 000 €	15 000 €
Rehabilitation - Forebay				30 300 €	30 300 €
Rehabilitation - pond	78 000 €	61 500 €	42 090 €	15 600 €	
Rehabilitation - soil filter					1 455 €
Reconditioning					7000 €
Total	**99 100 €**	**82 600 €**	**63 190 €**	**70 000 €**	**62 855 €**

The results show that the forebay solutions can lower cost of the stormwater treatment, as emptying of the pond is delayed. Forebay solutions are even more important when pond size increases, as suction dredging is a major cost post. Ponds without forebay can be reconstructed and equipped with a forebay after being emptied. When possible, dry excavation should be applied to lower costs associated with handling sediment.

As mentioned earlier upstream work minimizing the amount of sediment reaching the pond or soil filter facility is necessary to minimize rehabilitation cost. Sediment handled under dry conditions can be excavated with conventional front loader, it needs no dewatering and it is easily landfilled with low cost. The amount of sediment is usually small, after dewatering and, even if landfilling cost is high, the major cost contributor is when sediment is dredged. Limiting the need of dredging should be given the highest priority to lower cost.

Forebays and soil filters are well established and a preferred solution in Germany (ref). Before using this solution in Norway and Sweden, the effect of colder climate on the soil filter functions must be understood.

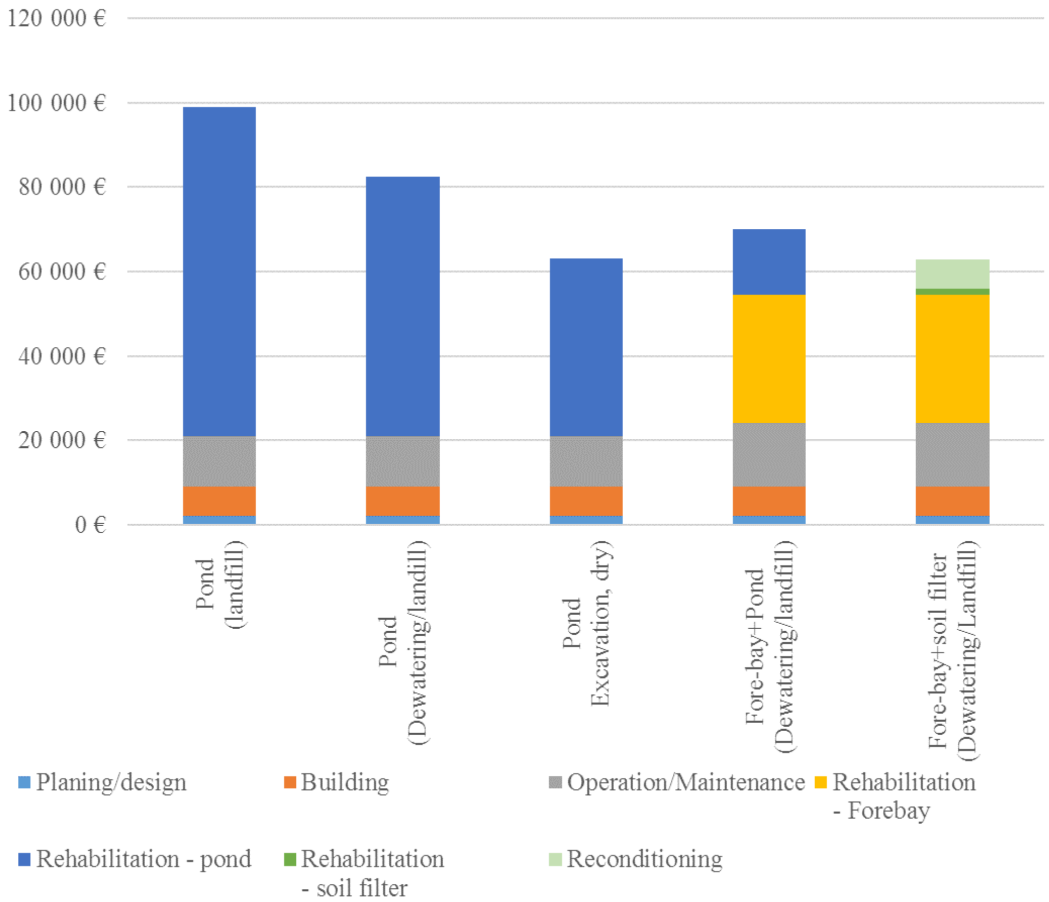


Figure 4.6 Rehabilitation cost of the three different treatment facilities after three decades.

5 SWOT- analysis

A SWOT analysis was carried out for analysing the strength, weaknesses, opportunities and threats regarding ponds, forebay+pond, forebay+soil filter. This decision-based method is widely used and can be applied to organizations, product, industry or person. In this case it was used to compare internal and external factors regarding treatment facilities, see Appendix B:1 and B2.

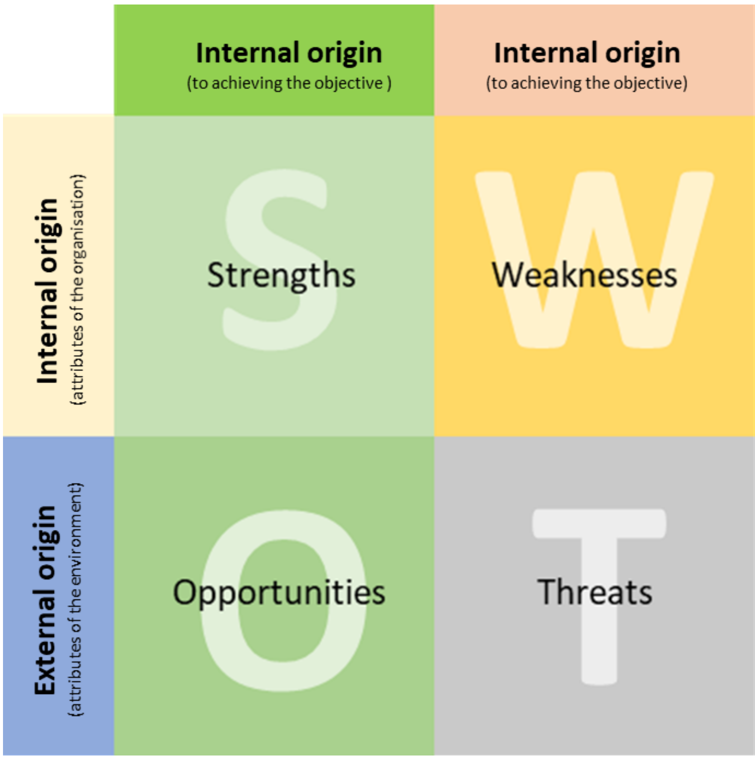


Figure 5. 1 SWOT-matrix for determining the strengths, weaknesses, opportunities and threats of treatment facilities. Illustration: Xhienne Wiki commons

Pond - Strength

Practitioners in Sweden and Norway have extensive experience in building and maintaining ponds. Ponds are relatively easy to plan, design and build and provide a robust solution; there is good removal of suspended material and particle bound metals, as well as good peak flow and retention capacity. Maintenance requirements of ponds are low and they appear to function despite large sediment loadings. Daily maintenance costs are therefore low, and there are ecological and recreational benefits.

Forebay + pond – Strength

Experience of building and maintaining combined forebay and ponds exists both within and outside the Nordic countries. The technology is easy to plan, design and build. The solution provides good removal of suspended material and particle bound metals, as well as good peak flow retention capacity, and can thus be considered robust. A forebay prolongs the life time of a pond, ensures continued functionality despite high sediment loadings and lowers the maintenance cost since it has low daily maintenance requirements (handled by contractors). It has the same ecological and recreational benefits as the pond solution.

Forebay + soil filter – Strength

Extensive experience within construction and maintenance of soil filters exists within Germany and Austria. Soil filters have good water retention capacity. Planning, design and construction of the technology is relatively easy, and it allows for visual inspection and monitoring of functionality. Removal capacity of suspended particles, metals and organic pollutants is excellent, and it has low daily maintenance requirements. A major strength of the forebay + soil filter solution is that sediment can be removed (excavated) without the need of dewatering and contractors can use standard equipment. Thus, rehabilitation costs and space requirements are low since there is no need for special equipment nor dewatering of the sediment. Moreover, also soil filters have unknown ecological value, rehabilitation action is generally not needed for a prolonged period.

Pond - Weakness

The variability between types of ponds constructed is very high, were different types can be found even along the same road, making inspection, monitoring and maintenance challenging. Pond maintenance is not currently prioritised in Sweden. Thus, ponds are not regularly monitored, and early warning signs of dysfunction are missed and only recognised once the system fails. Removal capacity of organic pollutants and dissolved compounds is low. For rehabilitation, dry excavation is not possible in most cases and most contractors lack the required dredging equipment. Consequently, rehabilitation cost and space requirements are high in order to dewater and handle the dredged sediment.

Forebay + pond – Weakness

Currently, there is a high variability of pond types. Regular maintenance of the forebay is very important and emptying of the forebay is required every two to three years. Functionality of the pond is, however, difficult to monitor and control. Generally, ponds are not efficient in removing dissolved compounds. Dry excavation is, in most cases, not possible and, subsequently, some contractors employ dredging. Suction dredging leads to high rehabilitation costs and space requirements around the facility in order to handle and dewater the dredged sediment.

Forebay + soil filter – Weakness

Soil filters have, to date, not been used in Sweden or Norway and would require pilot testing and possible tailoring for Nordic climatic conditions before implementation. Good control of upstream sediment flow is essential to ensure functionality, as there is a risk of clogging of the soil filters if they receive large sediment loads, in which case, rehabilitation is often required. Soil filters have a limited peak flow retention capacity and are of low recreational and ecological value.

Pond - Opportunities

Environmental authorities view ponds as an acceptable solution and/or minimum requirement in order to retain stormwater and improve the quality. There is potential that development of new methods to map depth and propagation of sediment could lower maintenance and rehabilitation costs. Rehabilitation costs could also be significantly lowered by accommodating for dry excavation within the pond design. To date, only few ponds have gone through rehabilitation in Sweden, but as more ponds are successfully rehabilitated, experience of managing the sediments will increase with time. Streamlining pond design and limiting the number of different types, would facilitate maintenance and sediment management. Good pond design, which takes into account sediment dredging and management, can reduce the establishing costs. If dry excavation methods could be employed, cost efficiency (€/ton sediment managed) could be considerably improved.

Forebay + pond – Opportunities

See opportunities under "Pond". With development of mapping sediment depth, improved handling of sediment and monitoring, environmental authorities will view this as a robust solution. Environmental authorities will require improved removal of organic pollutants, which a combined forebay/pond solution can meet. A forebay can extend the functionality and life-time of the pond, while the possibility of dry excavation decreases costs and thus improves cost efficiency (€/ton sediment managed).

Forebay + soil filter – Opportunities

Requirements to improve the removal of organic and dissolved pollutants will increase with time. The soil filter addresses this by acting as a filter and adsorbent and improves the removal of particles, colloids and dissolved organic and metal contaminants from the stormwater. Forebay/soil filter solutions meet the water quality requirements.

Environmental authorities will require regular and good control of system functionality, which can be met by forebay + soil filter solution. For forebay + soil filter solution visual inspection and monitoring of the facility is easily performed, since clogging results in notably slow infiltration. Clogging is indicated by a water table present in the soil filter for longer than 48 hours.

Requirements by the "problem owner"/user on cost efficiency will increase demands for low rehabilitation cost. For soil filter solution, rehabilitation is possible using standard excavation equipment and sediment can be handled under dry conditions. Consequently, rehabilitation costs are low and rehabilitation of the soil filter is required approximately every 25-30 years. The cost efficiency and high contaminant removal achievable using the forebay/soil filter treatment, makes this option an interesting alternative for further development and potential implementation.

Pond - Threats

It can be difficult to comply with requirements of proven treatment efficiency from environmental authorities, especially at certain sites, when using ponds only. There is a risk of continued failure in ponds due to a lack of monitoring and control. Due to the limited number of ponds installed as well as their small size, the management of dredged sediment remains under-developed and expensive, with a limited number of contractors to choose from. On-site dewatering requires more space than currently available, and insufficiently dewatered sediments lead to higher landfilling costs. There is also a risk that rehabilitation of ponds leads to disruption of the system and reduction in downstream water quality.

Ponds therefore have low cost efficiency (€/ton sediment managed) when compared to the other methods.

Forebay + pond – Threats

The functionality of the facility is dependent on the maintenance of the forebay. If dredging is chosen as a rehabilitation method the same risks are present as described in those for a pond (see “Pond – Threats”). Forebays, especially when dry excavation is employed, cannot be considered to have any recreational value. There is a risk that cost efficiency of the facility (€/ton sediment managed), can decrease if higher rehabilitation frequency is necessary than the estimated once in 20 years for the pond.

Forebay + soil filter – Threats

This facility is currently not widely used in the Nordic countries and thus may face difficulties in acceptance among the environmental authorities. There is a risk for underestimating costs and overestimating treatment capacity as well as the general lack of experience with the technology. There is a risk of large sediment loadings leading to clogged infiltration and increased costs, while cold climates may reduce soil filtration functionality and capacity. Consequently, there is a risk that the facility’s cost efficiency (€/ton sediment managed), could be reduced if higher rehabilitation frequency is necessary than the estimated once every 25 – 30 years for the soil filter.

6 Conclusions and recommendations

6.1 Guidelines

A between country comparison of guidelines and regulations shows that in Norway and Germany these have been updated and synchronised. The Swedish guidelines, however, need a corresponding review and synchronization since today's guidelines consist of recommendations, handbooks and publications written between 2003 and 2014. There is no guide to help the reader on how these documents relate to each other and circle references are problematic. Today's situation leads to uncertainty in terms of design, maintenance and rehabilitation of retention facilities.

This report suggests three main alternatives for future handling of stormwater sediments in Sweden, see Figure 6.1:

- Alternative management of sediment from retention facilities (ponds). Rehabilitation costs are considered when choosing a retention facility. Handbooks and recommendations are revised, maintenance is described in maintenance plans whose implementation and follow up become mandatory. Sediment is handled as dry as possible. Rehabilitation of old ponds includes the installation of a forebay. (The case in Norway today)

- Alternative techniques are developed and introduced. One promising retention facility is an infiltration magazine combined with a forebay. This method is generally used in Germany Austria and Switzerland, hence, existing guidelines must be prepared for Nordic climate conditions. This technique is maintenance dependent, but sediment is exposed to freeze and thaw cycles and can be excavated under "dry" conditions.

- Business as usual. Ponds are the preferred retention facility, and maintenance and rehabilitation are performed as today. Existing handbooks and recommendations are used, although a written guide to how these should be used is recommended. (The case in Sweden today)

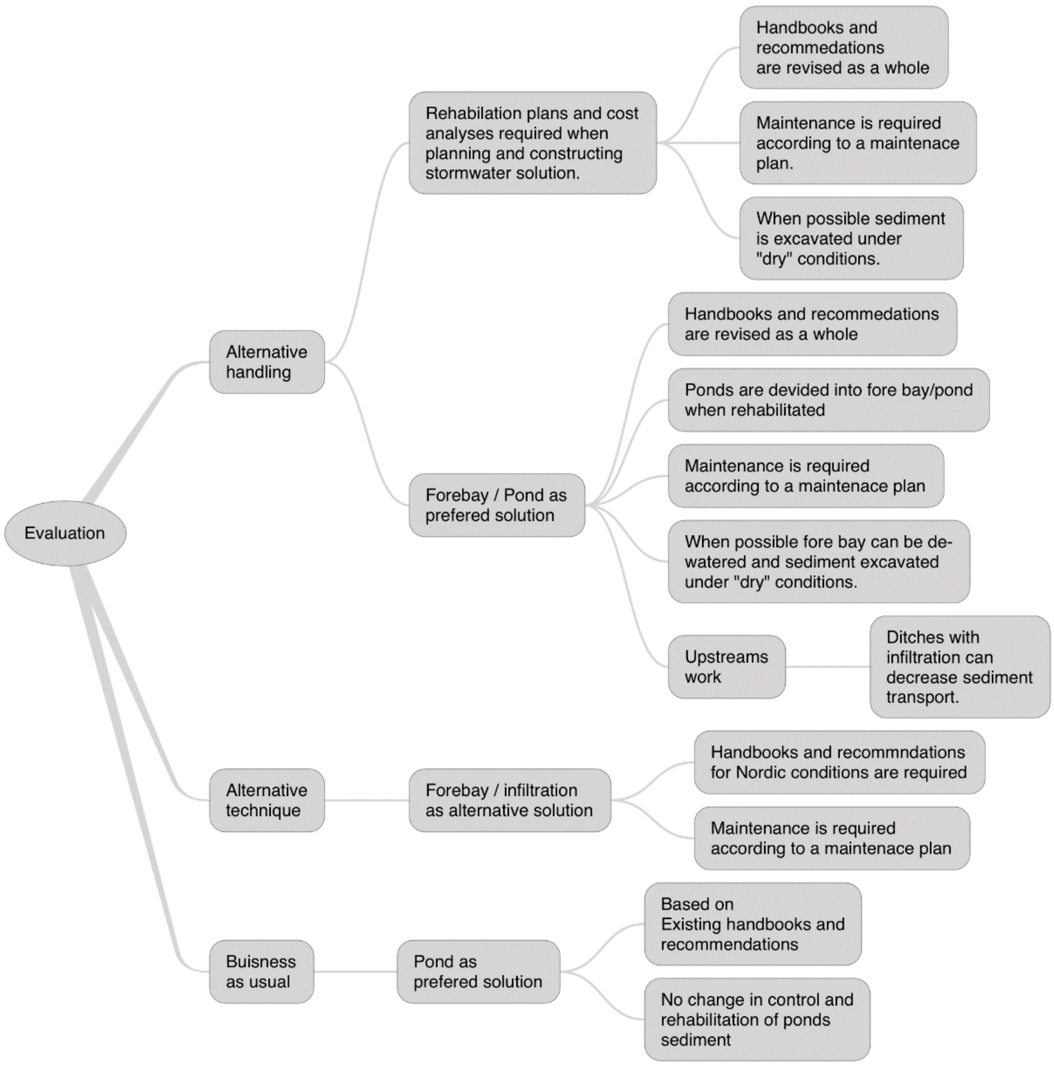
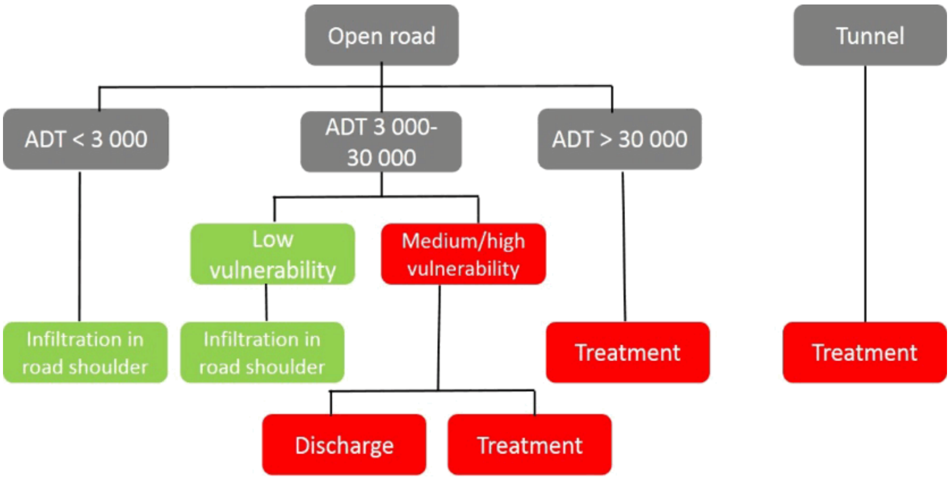


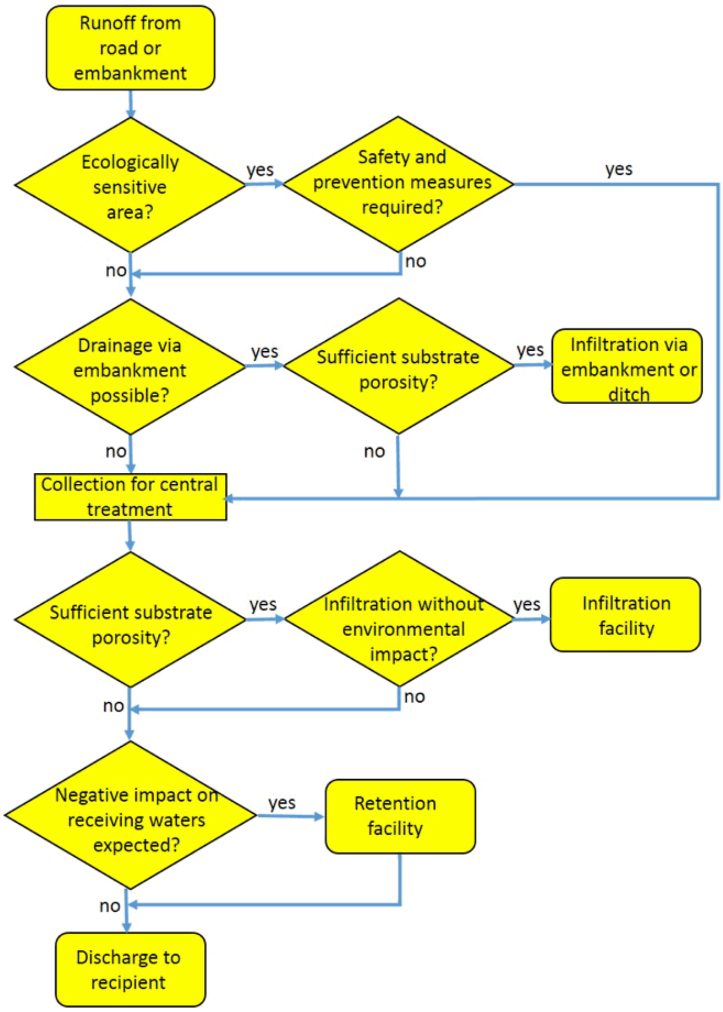
Figure 6.1 *Three main alternatives for future handling of stormwater sediment in Sweden*

6.2 Stormwater handling design charts

The Norwegian design chart uses ADT as a starting point to decide when treatment is necessary (Figure 6.2 left side), whereas the German design chart (right side) has a starting point in assessed ecological sensitivity. In both cases, when possible, local infiltration is promoted. The Norwegian design chart is based on ADT and vulnerability of the site. ADT < 3 000 is automatically assessed to represent low vulnerability. Low vulnerability equals with low ecological sensitivity of the area and/or low environmental impact when drainage water is infiltrated. The German design chart is primarily dependent on ecological sensitivity of the area, possibility for infiltration based on substrate porosity and environmental impact, i.e. expected negative effect on receiving waters.



a)



b)

Figure 6.2 a) Norwegian and b) German design charts.

We recommend updating the Swedish guidelines by combining the Norwegian and German designs chart (Figure 6.3 and Appendix X). ADT gives a good first estimate of the pollutant load from a road environment and the following evaluation starting points are suggested:

- ADT
- Vulnerability of the receiving water (= ecological sensitivity of the area and expected pollutant load and negative impact on receiving waterbodies).

With an ADT less than 3 000 the expected pollutant load and impact on receiving waterbodies is low, and local infiltration via embankment, road shoulder or ditch is promoted if the substrate porosity is sufficient (A).

For ADT between 3 000 – 30 000 in areas with documented low vulnerability, local infiltration via embankment, road shoulder or ditch is promoted if the substrate porosity is sufficient (A). In some areas, subbase porosity might hinder local infiltration and then stormwater collection to an infiltration facility where substrate porosity is sufficient is needed (B).

For ADT between 3 000 – 30 000, the vulnerability of the receiving water should be assessed since collection of stormwater is needed for areas with medium to high vulnerability. For areas with medium vulnerability, infiltration is possible depending on substrate permeability when pollutant load and negative impact on receiving waterbodies is considered low (A or B). For areas with high vulnerability and expected negative impact on receiving waters treatment in a retention facility is needed before water can be discharged (C).

ADT > 30 000 suggest that vulnerability is high and stormwater should be collected to a retention facility and treated before discharged to the receiving water (ground or surface waters) (C).

Roads with stormwater grid and tunnels are assessed in similar way as open roads with ADT > 30 000.

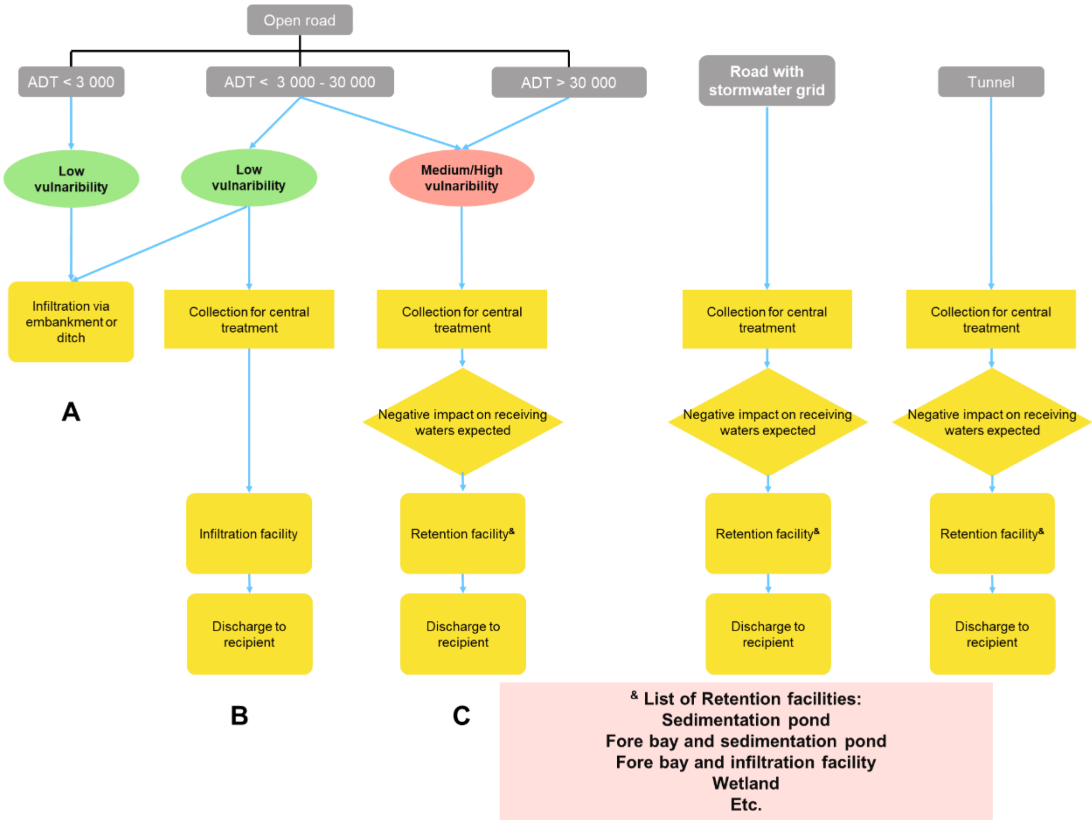


Figure 6.3 *Suggested assessment, based on ADT of the road, receiving water vulnerability of the area and estimated negative impact on receiving waters.*

When treatment is necessary due to pollutant load and negative impact on receiving waterbodies (vulnerability), stormwater is collected to a centralised treatment or retention facility. The treated water is subsequently discharged to the receiving ground- or surface waters.

6.3 Managing of stormwater sediment

Handling of sediment is costly and management costs increases with increasing water content. Pond systems where sediment must be dredged under water saturated conditions are the most expensive. Up to 60 - 70 % of the cost of sediment management originates from the dredging action. In a worst-case scenario rehabilitation cost are higher to much higher than the cumulative costs of building and maintenance.

Handling, transportation and landfill of large amounts accumulated sediments also imply negative impacts on the environment, mostly by carbon emissions. When possible, local infiltration of stormwater into embankments, road shoulders and ditches can minimize both sediment and contaminant transport. When infiltration is not possible due to substrate porosity, stormwater can be collected to an infiltration facility, a site where substrate porosity is sufficient to infiltrate.

When planning a retention facility, priority should be given to handling sediments with as low a water content as possible. When pond solutions are chosen, the possibility of a by-pass or re-direction of stormwater during remediation should be considered. Excavated sediment should primarily be handled on site and be exposed to natural drying processes before further treatment or transport to landfill. Repeated freeze and thaw cycles (F/T-cycles), can reduce the sediments total volume by 40 – 70 % due to consolidation. An alternative retention facility is an infiltration basin combined with a forebay. This solution is widely used in Germany and Austria, but the road administrations of Norway and Sweden thus far have little or no experience with its functioning under cold climate conditions. Forebay and infiltration facilities can provide better water retention than ponds. In this case, accumulated sediment is exposed to F/T-cycles which reduces its volume and prolongs the facilities service time. Infiltration facilities with forebays that can be emptied when dry (bypass possibility) will provide high cost efficiency. The quality of the discharged water will also be much better than with the use of conventional stormwater ponds.

Infiltration basins combined with a forebay are to be considered good potential stormwater treatment facilities but may require further development to function in cold climates. As municipalities and other actors face the same requirement to develop new methods for reducing remediation costs, improving water quality and increasing water retention capacity, development efforts should be coordinated with these other actors.

6.4 Recommendations

- When a retention facility is planned and designed its rehabilitation cost should be taken into consideration. A major part of the total life cycle cost derives from rehabilitation and sediment handling.

    - When retention facility is chosen, it should be considered to manage the accumulated sediment as dry as possible, as management cost of sediment increases with increasing water content.

    - Always consider the possibility of a by-pass or re-direction of stormwater during remediation.

    - Reserve an area adjacent to the retention facility for handling and dewatering of sediment.

    - Freeze and thaw cycles reduce water content in exposed sediment. Volume reduction of 40 – 70 % is possible when sediment is exposed to several F/T-cycles.

- Prepare separate guideline defining requirements for preventative measures for accidents with hazardous substances.

6.4 Future R&D needs

The following needs are concluded:

- Guidelines for choice of treatment, based on site specific conditions are needed. The choices are between no treatment versus local treatment or centralised retention facility.

Treatment type depends on expected pollutant load and environmental impact on groundwater and receiving waterbodies.

- Recommendations for design of local treatment types (road embankment, -shoulder and trenches).
- Recommendations for design of centralised treatment types (ponds, sedimentation- and infiltrations facilities). These should be designed based on the same principles, as this can facilitate maintenance and rehabilitation.
- A standard evaluation method to define low, medium and high ecological sensitivity (ES).
- Describing the level of accepted environmental impact to the groundwater environment due to infiltration.
- Describing the level of negative impact on receiving waters (surface water) from open roads with different ADT.

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Appendix A - Intervjuunderlag

Inledning
Denna enkät och intervju genomförs inom ramen för projektet REHIRUP (Reducing Highway Runoff Pollution) och utförs på uppdrag av Trafikverket.

Enkäten ligger till grund för en kunskapssammanställning inom Trafikverket. Motsvarande intervju kommer att göras med andra aktörer i Sverige och i Norge. Enkätfrågorna skickas ut i förväg och besvaras muntligen på telefon. Målet är att på nationell nivå få en överblick av trafikverkets hantering av dagvatten och hur trafikdagvattenanläggningar utformas och sköts. Du behöver därför inte kunna redovisa exakta siffror, dina uppskattningar är tillräckliga för detta ändamål. **Svara på de frågor som är relevanta för ditt arbetsområde. Vi bedömer att det tar cirka 1 timme att svara på frågorna**. Resultaten från sammanställningen kommer att redovisas officiellt men inga uppgifter från enskilda intervjuer kommer att lyftas ut.

Detta delprojekt har som mål att sammanställa:

- Bakgrund till dagvattenanläggningar: syfte och behov
- Utformning och dimensionering av dagvattenanläggningar
- Erfarenheter av från dagens dagvattenanläggningar med avseende på:
  - lämplighet
  - problem
  - underhåll
  - sedimenthantering

Syftet med REHIRUP är att ta fram en rekommendation till underhåll av dagvattenanläggningar och förslag till dagvattenhantering som bidrar till:

- -tydligare underhållsplaner
- -effektivare reningsanläggningar (med bättre underhåll)
- -ökad användning av sediment istället för deponering

Intervjufrågor
Del A. Inledning -Om den intervjuade
Namn: ....
Roll i organisationen: ....
Ansvarsområde geografiskt: ....
Datum för intervjun:..
Vem som intervjuar:...

Kryssa i nedan enligt följande:
A: Vad är din kunskapsbas?
B: Vad ingår i dina nuvarande arbetsuppgifter.

	Planering i tidiga skeden	Utformning/ Bygghandling	Upphandling	Entreprenad/ Byggande	Drift- och underhåll	Dagvattendammar	Sedimenthantering	Annat
A								
B								

Hur länge har du jobbat i branschen?

0 – 5 år	6 – 10 år	11 – 15 år	16 – 20 år	> 21 år

Hur länge har du jobbat med frågor som berör vatten ur ett miljö perspektiv?

0 – 5 år	6 – 10 år	11 – 15 år	16 – 20 år	> 21 år

Arbetar du med **planering och investering gå vidare till B**:
Arbetar du med **drift gå vidare till C**:

Del B. Utformning av dagvattenanläggningar – Planering & investering

1. Vad styr val av dagvattenreningsanläggningar?
   - a. Vad avgör om det behövs en reningsanläggning eller ej? (krav från tillsynsmyndighet, av TrV fastställd praxis beroende på exempelvis storlek på väg eller ÅDT, förslag från utredande (miljö)konsulter, förslag från projekterande konsulter, annat?)
   - b. Vad avgör vilken typ av anläggning som väljs, hur påverkar miljökraven på val och typ av anläggning?

   Är det ofta samma typ eller varierar det?
   - c. Vem tar beslutet om en anläggning ska byggas?

   Anser du att välgrundade val görs?
   - d. Har miljökvalitetsnormerna för vatten påverkat ert arbete / bedömning av åtgärder?
   - e. Tänker ni på skötsel, underhåll eventuell sedimenthantering vid planeringen av anläggningen?

2. Dimensionering och utformning
Har du kännedom om dimensioneringsgrunder och andra parametrar som är styrande?

Vilka delar tas hänsyn till i utredningen?	Ja (x) / Nej (-)
Områdets Hydrologi	
Geology/topografi (nat. avrinning saknas)	
Befintligt Vegetation utströmningsområden	
Jordartsförhållanden	
Befintligt avvattningssystem	
Tillståndsbedömning av ex en trumma	
Riskbedömning, olyckor	
Trafikintensitet	
Lagstiftning (Krav från lst, etc)	
Kostnad	
Byggkostnad	
Drift- och underhåll	
Avveckling	
Vattendirektivet, MKN	
Rena dagvatten	
Fördröja dagvatten	
Skydda recipient	
• **Markmiljö**	
• **Vattenrecipient**	
• **Vattentäkt**	

3. Vilka dokument och riktlinjer används som underlag för utformning av dagvattenanläggningar?

Vilka Trafikverksdokument/riktlinjer används som underlag för detta?
Hur ser prioriteringen ut mellan olika dokument? Vilka används alltid, ofta, ibland?
Vilka externa dokument/riktlinjer används? Svara i tabellen nedan.
Är det något ytterligare dokument som används?

Exempel på dokument –

Dokument		Ja (x) / Nej (-)
Trafikverkets tekniska krav för avvattning	**TDOK 2014:0045**	
Trafikverkets tekniska råd för avvattning	**TDOK 2014:0046**	
Avvattningsteknisk dimensionering och utformning	**TDOK 2014:0051**	
Vägdagvattendammar -en undersökning av funktion och reningseffekt	**2003:188**	
Dagvattendammar om provtagning, avskiljning och dammhydraulik		
Vägdagvatten Råd och rekommendationer för val av miljöåtgärd	**2004:195**	
Vägdagvatten – Råd och rekommendationer för val av miljöåtgärd	**2011:112**	
Rening av vägdagvatten, Preliminära råd vid dimensionering av enklare reningsanläggningar	**Publ.98:009.**	
Skötsel av öppna vägvattenanläggningar.	**2008:30**	
Öppna vägdagvattenanläggningar – Handbok för inspektion och skötsel	**2015:147**	
Vägdagvattenanläggningar inventering, Kartläggning och inventering av Vägdagvattenanläggningar 2014-11-27		
P 90 Dimensionering av allmänna avloppsledningar, Svenskt Vatten		
P 110 Avledning av dag-, drän- och spillvatten, Svenskt Vatten		

4. Anläggningsentreprenader för dagvattenanläggningar
   a. Sker det sällan eller ofta avsteg från projekteringshandlingarna?
   b. Har entreprenörerna rätt kompetens för att anlägga vattenanläggningar?
   c. Uppstår det sällan eller ofta problem vid entreprenaden?
   d. Har besiktningsmännen god kompetens för att bedöma om anläggningarna utförts på rätt sätt?

5. Överlämning av anläggningar (samma frågor finns även under driften)
   a. Hur sker överlämning av ny anläggning till driftansvariga?
   b. Vilken information överlämnas (utredningar, ritningar, driftsinstruktioner, skötselplaner)?
   c. Hur vidarebefordras denna kunskap till driftentreprenörer? Hur görs det vid byte av entreprenör?
   d. Hur samlas handlingar in i NVDB? Använder ni den för att lägga in, byggår, dimensioneringshandlingar, tömning mm?

Del C.– Drift och underhåll

<u>Beskrivning av verksamheten</u>

Svara övergripande eller genom att fylla i tabellen nedan

1. Hur många dagvattenreningsanläggningar har ni i ert driftområde?
2. Vilka typer av anläggningar har ni?
3. Vilken är den vanligaste hanteringen av dagvatten?
4. När är dagvattenanläggningarna anlagda och varför?
5. Är det fler anläggningar planerade?

Dagvattenanläggningar

Namn	Placering	Anlagd år	Avvattnar yta ha?	A. Typ av anläggning (se förslag nedan)	B. Funktion (se förslag nedan)	Drift vilken hur ofta

Fyll i siffrorna under kolumnerna i tabellen ovan, flera beskrivningar kan passa in.

A. Typ av anläggning	
1. Dike	
2. Sedimentationsdamm	
3. Fördröjningsdamm	
4. Våtmark	
5. Översilning	
6. Infiltrationsanläggning	
7. Avsättningsmagasin	
8. Övrigt	

B. Funktion	
1. Rening	
2. Fördröjning	
3. Skydd vid olyckor	
4. Övrigt	

Drifterfarenheter som grund för utformning av nya anläggningar

1. Är du involverad i tidiga skeden för de anläggningar du kommer att få underhållsansvar för?
2. Tas dina och andra drifterfarenheter till vara vid utformning av nya anläggningar?

Överlämning av anläggningar

1. Hur sker överlämning av ny anläggning till driftansvariga?
2. Vilken information överlämnas (utredningar, ritningar, driftsinstruktioner, skötselplaner)?
3. Hur vidarebefordras denna kunskap till driftentreprenörer? Hur görs det vid byte av entreprenör?
4. Finns ett systematiserat sätt att hantera denna information? Samlas handlingar t.ex. i digitalt arkiv?

Anläggningarnas funktionalitet

1. Går det att se om anläggningarna fungera som planerat?
2. Har de en flödesutjämnande funktion (när de är avsedda för det)? Går det att se att de fylls vid regn och långsamt tappas av därefter? Görs det kontroller mot hur de dimensionerats avseende fyllning och avtappning?

3. Fungerar reningen? Kontrolleras detta? I så fall hur (exempelvis vattenprovtagning som stickprov eller flödesproportionella prover eller kontroll av sedimentuppbyggnad).
4. Fungerar de som olycksskydd? Hur ofta görs sanering av exempelvis oljeutsläpp i anläggningarna?

Generellt fungerar anläggningarna som olycksskydd om de är konstruerade för det, annars inte.

Egenkontroll och tillsyn

1. Sker egenkontroll av anläggningar?
2. Vem är ansvarig för att egenkontrollen genomförs?
   a. Vem ansvarar för att det sammanställs/rapporteras och läggs in i NVDB?
   b. Finns det skötselprogram för anläggningen?
3. Vilka krav ställs på detta från tillsynsmyndigheter?
   a. Finns krav på årsredovisningar av reningsresultat eller på utförd tillsyn och underhåll?
   b. Hur ofta sker tillsyn av anläggningarna?
4. Genomförs korrigerande åtgärder ofta eller sällan?
   a. Vilka är de vanligaste återkommande problemen?

Löpande underhåll (ej sedimentrensning)

1. Hur ofta görs underhållsinsatser i anläggningarna?
2. Vilka parametrar tas med vid bedömning av underhållsbehovet?
3. Vem sköter underhållet (speciell entreprenör för dagvattenanläggningar eller samma entreprenör som för vägunderhållet)?
4. Vad görs normalt i det löpande underhållet/skötseln (exempelvis mindre rensning vid in-. och utlopp, klippning av vegetationen, klippning av slänter och angränsande grönytor)?
5. Vilka problem är kopplade till skötsel och underhåll? (exempelvis: vet inte hur, vet inte när, oklart vem, svårt att komma dit)

Rensning av sediment – här beskrivs gärna några exempel på genomförda åtgärder

Har ni tömt sediment i några dammar eller andra anläggningar?

Hur ofta görs tömning av sediment (hur många års intervall)?

Del E. Ekonomi

1) Kostnader

Ungefärlig kostnad för skötsel av en damm/anläggning? Enheten per anläggning eller kvm väg etc.

- hela systemet
- byggnation
- underhåll
- förberedelse av tömningsåtgärd
- sedimenttömning
- sediment hantering etc

Hur överensstämmer budgeten för sedimenttömning med de verkliga kostnaderna för hela underhållsåtgärden?

Del F. Kunskapsbehov

Med utgångspunkt av intervjun, uppfattar du någon specifik fråga/inriktning som är extra viktig att arbeta vidare inom?

<u>Följdfrågor kring sediment:</u>

Vilka hanteringsalternativ har du för hur uppsamlat vatten/sediment hanteras

<u>Föroreningsbelastning till dagvattenanläggningar</u>

Hur är sedimentkvalitén på det som finns i reningsanläggningen?
Påverkar kvalitén av sedimentet valet av metod skötsel/tömning?
Hur kontrolleras reningseffekten på fasta och lösta föroreningar (näringsämnen, tungmetaller, organiska ämnen)?

<u>Sedimenttömning och sedimenthantering</u>

Hur många dammar har ni slamtömt och vilka är era erfarenheter utifrån det?
Hur mycket sediment bedömer du töms vid varje tillfälle (ton/m2 damm yta)?
Vad vet man idag om den långsiktiga sedimentkvalitén?
Hur stor andel av dessa sediment är karakteriserade som:

- Inert avfall
- Icke-farligt avfall
- Farligt avfall

Hur stor andel är finkornigt respektive grovkornigt, och skiljs dessa åt?

Vilka parametrar ingår när sedimenttömning planeras och utförs och volymen sediment bedöms?

Parametrar	Ja (x) / Nej (-)
Densitet	
• **Skrymdensitet**	
• **Torrdensitet**	
Kornstorlek	
• **Siktning**	
• **Sedimentation**	
Organiskt innehåll (TOC)	
Sedimentmaterialets vattenkvot/TS	
Sedimentmaterialets föroreningsgrad	
• **Metaller**	
• **Organiska föroreningar (PAH, olja etc)**	
• **Mikroplaster**	
• **Lakningsegenskaper (L/S = 10)**	
• **Etc..**	
Tillgänglighet (vägar, uppställningsplats)	
Metod för sedimenttömning	
• **Sugmuddring**	
• **Miljöskopa**	
Hantering på plats/ avvattning	
Avyttring (deponering/återanvändning)	

Appendix B:1 - SWOT - Strength and weaknesses

Strength *(helpful to achieve objectives)*			**Weaknesses** *(harmful to achieve objectives)*			
Pond	Fore bay + Pond	Fore bay + soil filter	Pond	Fore bay + Pond	Fore bay + soil filter	
Long practice to build and maintain	Nordic and international practice to build and maintain	German & Austrian practice to build and maintain	Many different solutions today. Maintenance is not proiritized	Many different solutions today. Maintenance is not proiritized	Needs to be costumized to Nordic climate conditions	**Build**
Easy to plan, design and build	Easy to plan, design and build	Easy to plan, design and build			New for Nordic countries	**Plan, design**
Robust solution	Robust solution	Excellent control of function (easy to see when it is not functioning).	Function of the facility is difficult to monitor and control	Function of the pond is difficult to monitor and control	Needs good control of upstreams sediment flow.	**Function**
Good removal of suspended material and metals	Good removal of suspended material and metals	Excellent removal capacity of suspended partickles, metal and organic pollutants.	Low removal of organic pollutants	Low removal of organic pollutants	Removal function of soil filters is sensitive to large sediment loads	**Removal function**
Good peak flow retention	Good peak flow retention				Limited peak flow retention	**Peak flow**
Works (seemingly) after large sediment loads	Works after large sediment loads			Forebay needs to be emptied every second or third year	Rehabiltation nedded after large sedimentation loads	**Large sediment load**
Robust, low maintance requirements	Robust, low maintance requirements	Low maintance requirements				**Maintance**
		Sediment can be removed without the need of dewatering.	Dry excavation is not possible in most cases	Dry excavation of the pond is not possible in most cases		**Sediment handeling**
	Many contactors can operate to empty the forebay	Many contractors can operate as no special equipment is needed	Few contractors have suction dredging equipment	Few contractors have suction dredging equipment		**Contactors**
Low maintenance costs	Fore bay increases the ponds life time and lower maintenence cost	Low rehabilitation cost	High rehabilitation cost. Suction dredging is needed.	High rehabilitation cost. Suction dredging is needed.		**Maintanace cost**
		No need for space around the facility to dewater and handle sediment	Needs space around the facility to dewater and handle sediment	Needs space around the facility to dewater and handle sediment		**Space**
Recreational benefits	Recreational benefits				Low recreational and ecological value	**Value**

Appendix B:2 - SWOT - Opportunities and threats

Opportunities *(helpful to achieve objectives)*			**Threats** *(harmful to achieve objectives)*			
Pond	Fore bay + Pond	Fore bay + soil filter	Pond	Fore bay + Pond	Fore bay + soil filter	
Accepted /required by the environmental authorities	Accepted /required by the environmental authorities		EPA can require proved treatment efficiency		May not be accepted by the environmental authorities	**EA**
Development of mapping sediment depth and expansion can lower maintenance costs	Development of mapping sediment depth and expansion can lower costs	Easy to monitor sediment amount and improve efficiency	Lack of control/monitoring leads to failours of pond facilities			**Monitoring**
Development of dry excavation possibilities can decreas costs	Fore bay combined with dry excavation can decrease costs	Decreases maintenance and costs			Lack of experience, underestimated cost for maintanance and/or overestimated treatment capacity.	**Maintance/ cost**
Experience of handling sediment increases with time		Easy to monitor sediment amount and the function of the facility	Higher landfilling cost. Higher environmental requirements on sediment handling		Large sediment loads clogg infiltration and increase costs	**Sediment**
Development of standard pond solutions for a few sediment alternatives		Rehabilitation with ordinary excavation equipment	Dependent on cost development on suction dredging	Dependent on cost development on suction dredging		
		Needs rehabilitaions after 25 - 30 years or more	Few companies on the dredging market	Few companies on the dredging market		
		High cost efficiency expressed as €/ton sediment landfilled	Low cost efficiency expressed as €/ton sediment landfilled	Low cost efficiency expressed as €/ton sediment landfilled		
			Dewatering on site needs space than available			**Space**
			Rehabilitation can disturb function of the facility and downstream water quality			**Rehabilitatio n**

Appendix C - Decision tree for treatment of stormwater

The following decision tree for treatment of stormwater is suggested:

A. Open road, ADT < 3 000 - 30 000 combined with an estimated low vulnerability and no negative impact on receiving waters:

- Infiltration via embankment and ditch, when local substrate permeability is sufficient.
- Discharge to receiving water, ground or surface waters

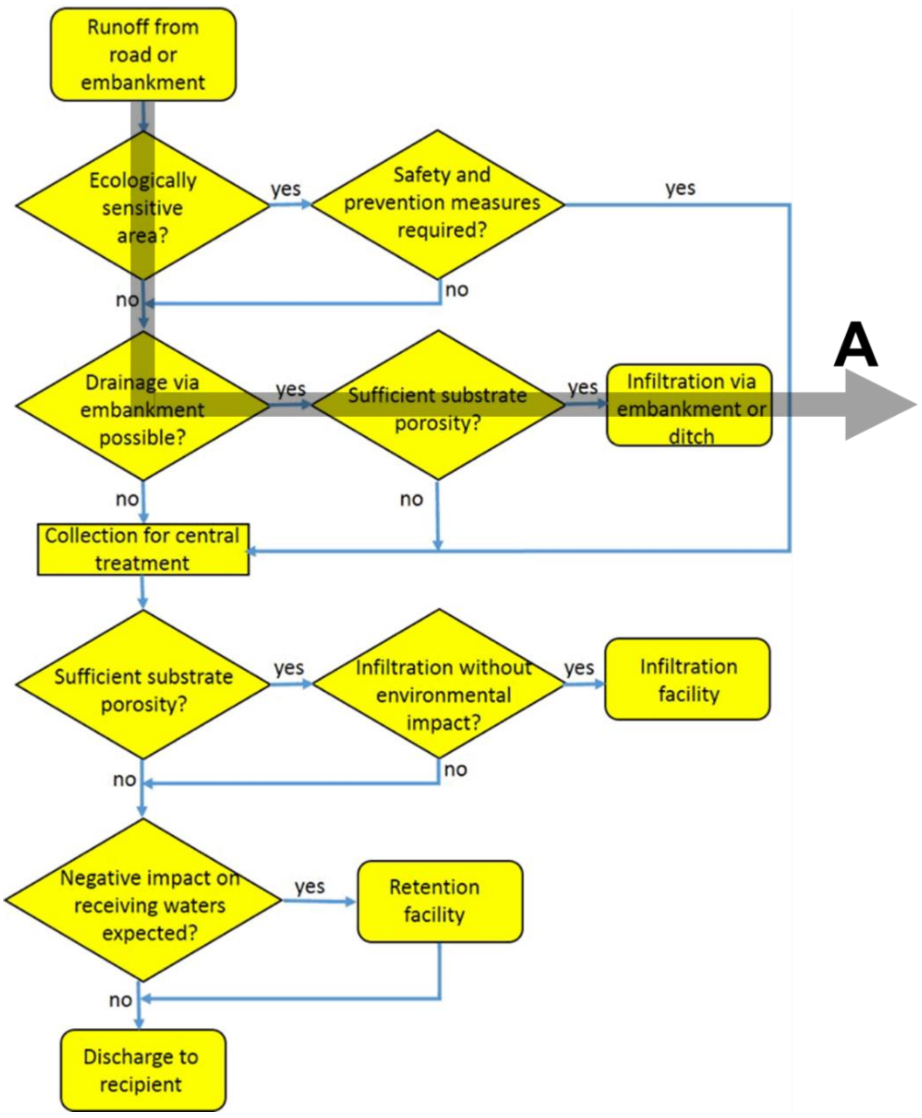

Figure C.1 Suggested design chart, for open roads with ADT < 3000 (A) and open roads with ADT 3 000 – 30 000 and where vulnerability of the area is assessed as low.

B. Open road, ADT 3 000 - 30 000, and an estimated medium vulnerability of the area but where infiltration is possible without environmental impact:

- Collection and infiltration via infiltration facility with sufficient substrate permeability.

- Discharge to receiving ground or surface waters

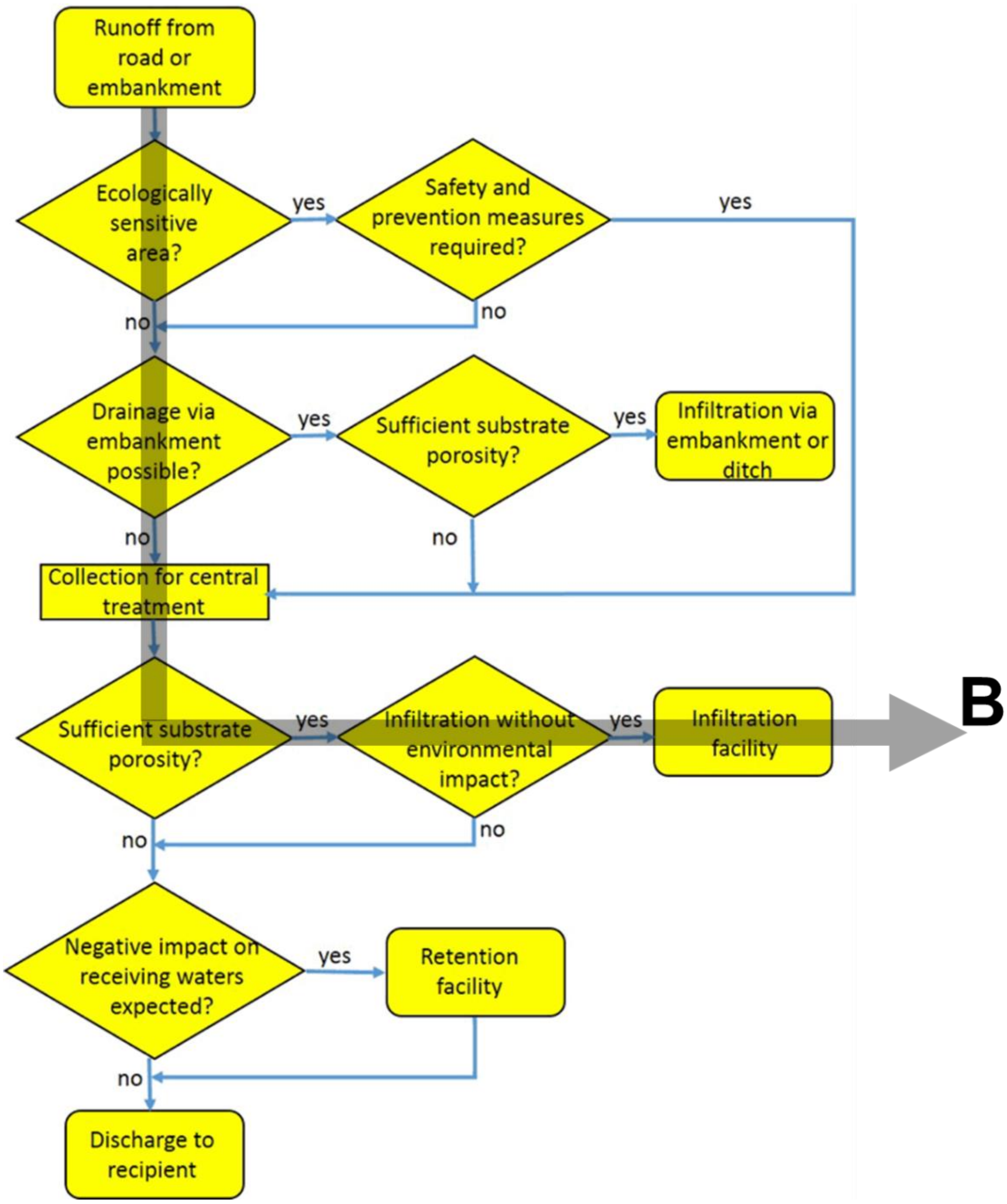

Figure C.2 Suggested design chart, for open roads with ADT 3 000 – 30 000 and where vulnerability of the area is assessed as low.

C. Open road, for ADT 3000 - > 30 000 and an estimated high vulnerability and negative impact on receiving waters:

- Retention facilities before discharge to receiving water. Retention in pond, forebay/pond or forebay/infiltration facility before water is discharged.

- Discharge to receiving ground or surface waters.

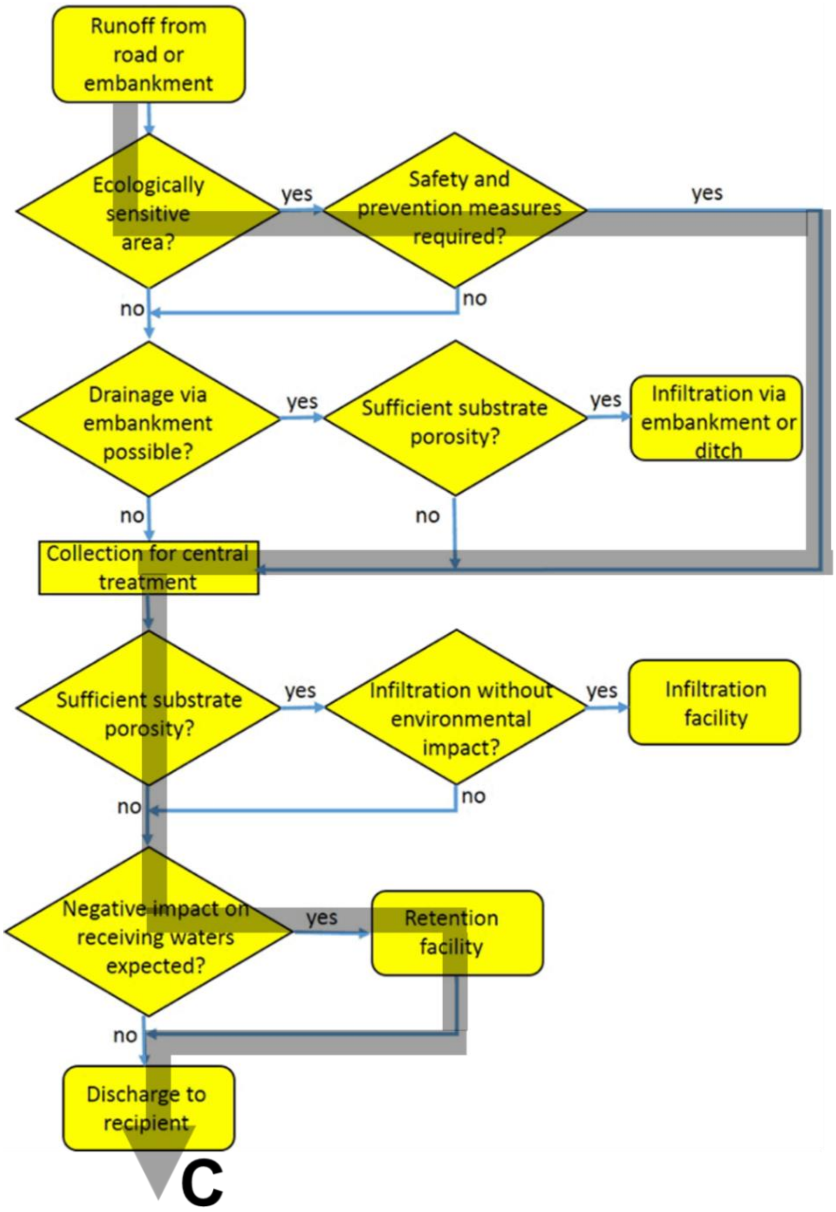

Figure C.3 *Suggested design chart, for open roads with ADT < 30 000 (3a) and open roads with ADT 3 000 – 30 000 and where vulnerability of the area is assessed as low (2a).*

TRAFIKVERKET

Trafikverket, XXX XX Ort. Besöksadress: Gata XX.
Telefon: 0771-921 921, Texttelefon: 020-600 650

www.trafikverket.se