



Report concerning techniques to reduce litter in waste water and storm water

Katja Norén, Kerstin Magnusson, Klara Westling, Mikael Olshammar

IVL Swedish Environmental Research institute

Agreement: 3804-14

**Commissioned by the Swedish Agency for Marine and Water
Management**

Published at: www.smed.se

Publisher: Swedish Meteorological and Hydrological Institute

Address: SE-601 76 Norrköping, Sweden

Start year: 2006

ISSN: 1653-8102

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1 Definitions/Glossary

Definitions of glossary and acronyms appearing in the report:

Best Available Technology (BAT)	As defined in Appendix 1 of the OSPAR Convention BAT “means the latest stage of development (state of the art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste”.
Best Environmental Practice (BEP)	BEP according to the OSPAR definition means “the application of the most appropriate combination of environmental control measures and strategies”.
Combined sewer system	Networks of underground pipes that convey domestic sewage, industrial waste water and storm water runoff in the same pipe to a centralised treatment facility.
Colloid	A mixture in which one substance of microscopically dispersed insoluble particles is suspended throughout another substance. To qualify as a colloid, the mixture must be one that does not settle or would take a very long time to settle appreciably.
Domestic waste water	Waste water from residential settlements and services, which originates predominantly from the human metabolism and from household activities (Directive 91/271/EEC).
Emerging substances	Not necessarily new chemicals. They are substances that have often long been present in the environment but whose presence and significance are only now being elucidated.
Green Infrastructure (GI)	Extended use of vegetation in urban areas, for instance green roofs, raingardens as well as permeable surfaces.
Industrial waste water	Industrial waste water’ means any waste water which is discharged from premises used for carrying on any trade or industry, other than domestic waste water and run-off rain water (Directive 91/271/EEC).
Low Impact Development (LID)	An onsite design using green roofs and swales instead of end-of-pipe solutions for storm water, with the aim to attain a natural hydrology.
Marine litter	Any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment. It also includes materials transported into the marine environment from land by rivers, draining or sewage systems or winds. It includes any persistent, manufactured or processed solid material. (OSPAR-definition)
Microscopic litter (microlitter)	Microscopic litter is in this report defined as litter items in size between 1 µm and 5 mm, which is the most commonly used definition, even if other exist. The lower limit comes from the fact that most manufactured particles (sometimes referred to as microspheres) are down to 1 µm in size. Another definition includes particles down to 0.1 µm which complements the size definition of nanoparticles below.
Nanoparticles	Particles between 1 and 100 nanometers in size.
OSPAR	The mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic. OSPAR started in

	1972 with the Oslo Convention against dumping and was broadened to cover land-based sources and the offshore industry by the Paris Convention of 1974. These two conventions were unified, up-dated and extended by the 1992 OSPAR Convention. The new annex on biodiversity and ecosystems was adopted in 1998 to cover non-polluting human activities that can adversely affect the sea.
Overflow	Release of untreated or moderately treated waste water to the environment due to a hydraulic overload in the sewer system or in the WWTP.
Separate sewer systems	Networks of underground pipes that are designed to convey waste water and storm water in separate pipes.
Source control	To prevent pollution with the help of site design and a deliberate choice of building material.
Suspension	A heterogeneous mixture containing solid particles that are sufficiently large for sedimentation. Usually they must be larger than one micrometer. Particles of suspension are visible to the naked eye
Storm water	Water from rain or melting snow that runs off urban surfaces. Storm water is either drained into the sewage system and treated in a waste water treatment plant (“combined system”), or transported separately to the receiving water with or without storm water treatment (“separate sewer systems”).
Sustainable Drainage Systems (SuDs)	Same as LID
Total suspended solids (TSS)	The dry-weight of particles trapped by a filter (normally 1.5-micrometer pore size).
Ultrafiltration (UF)	Variety of membrane filtration in which forces like pressure or concentration gradients lead to a separation through a semipermeable membrane. Suspended solids and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate.
Urban waste water	Urban waste water (often just waste water) is domestic waste water or the mixture of domestic waste water with industrial waste water and/or storm water-(Directive 91/271/EEC).
Waste water treatment plant (WWTP)	A facility where waste water is treated. It normally includes mechanical (primary treatment), biological (secondary treatment), and chemical (tertiary treatment) processes to remove contaminants and produce environmentally safe treated effluent water. A by-product of sewage treatment is a semi-solid waste or slurry, called sewage sludge, that has to undergo further treatment before being suitable for disposal or land application.

2 Summary

The scope and the objective of this project was to compile a report containing information of the best available technology (BAT) to reduce litter in waste water and storm water, as part of the OSPAR regional action plan against Marine litter, Action 42.

Litter items consist by definition of a number of different materials such as plastic, rubber, paper, metal, glass and textile and a combination of these materials. Among them, plastic is considered to be the most problematic. The transport, fate and harmful effects caused by litter on marine life depend on the size, shape and, in the case of plastic, the composition of the items.

The microplastics found in the North Sea and probably in the whole OSPAR region come predominantly from the region itself and not from the surrounding sea areas. Globally marine litter is considered to be dominated by land-based sources; especially since the adoption of the MARPOL Convention, the London Convention and the Oslo Convention (OSPAR) regulating dumping at sea, though there are regional differences.

A broad range of EU policies and legislation relate to marine litter, addressing both its sources and impacts. This includes EU legislation related to environmental legislation on waste management, urban waste water or pollution from ships, and specifically the Marine Strategy Framework Directive descriptor 10.

Marine litter from land based sources reach the North Sea by discharge of storm water, waste water, littering or atmospheric deposition, either directly to the North Sea or in its catchment area and further transported by rivers and other water ways to the sea. Whereas the sources to marine litter, and to some extent also the quantities of litter released from these sources, are fairly well investigated, information on the relative importance of the different pathways is still limited.

Storm water treatment

Important sources of litter in storm water are considered to be deliberate and undeliberate littering, wear caused by traffic, wear in connection to maintenance of infrastructure, boats and cars, industrial storm water, wear from artificial turfs, and atmospheric deposition. Production and handling of industrial plastic pellets is still considered to be a large source of plastic, and these pellets may also be transported with storm water depending on the location of the spill. Although there still are a lot of uncertainties there is today a fair amount of data on quantities of litter emitted from these sources. However, there are few studies on the transport of litter to the storm water, reduction of litter by storm water treatment technologies and final load of litter on the marine environment from storm water.

Up to date very few scientific papers are available on techniques to reduce different size classes of litter in storm water, and information on the cost for these techniques is also very limited. To our knowledge no scientific papers are targeting reduction of microscopic litter in storm water treatment facilities. The information forming the base for the present report on reduction of microscopic litter has been compiled from non-peer-reviewed reports and a survey that was directed to OSPAR-members within the working group for the Regional Action Plan (RAP) on Marine Litter. Installation costs and running costs per technology have been retrieved mainly from communications with retailers in Sweden and from the few scientific papers available. Methods studied include various types of Low Impact Development (LID), litter traps, wet-basin ponds, wetlands, filters, detention- and infiltration areas, but also more technical solutions such as hydro-dynamic separators. In the scientific literature, practices for street sweeping, emptying of catch pits, installation of grates over catch pits, frequent collection of litter and education programs are stressed as important and cost efficient measures to reduce large litter, but the focus in this study has been on treating litter in storm water.

Conclusions on storm water:

- The information on transportation of litter from source to storm water, and from storm water to the sea is sparse and relies on screening studies based on few samples. Research is needed to describe the processes and the magnitude of the load of litter from storm water to the sea, especially regarding microscopic litter.
- Most storm water in the OSPAR region is not treated at all today so installation of storm water treatment facilities in exposed areas is recommended. Conventional treatment systems like grids followed by wet-ponds would reduce the litter load from storm water to sea substantially. To improve the reduction of microlitter in storm water additional filtration and/or chemical precipitation is needed.
- Investment- and maintenance cost for storm water treatment facilities differs substantially between different technologies and locations, but all facilities needs proper maintenance to avoid clogging and malfunctioning.
- Storm water should preferably not be treated in municipal waste water treatment plants while high flow variability, low water temperature and pollutions will impair the treatment and deteriorate the sludge quality.
- Low impact development mimicking the natural hydrology in urban area has a good potential to reduce the load of litter to the sea. The storm water volumes will be reduced, and the increased visibility of the storm water in the urban

environment is likely to reduce the deliberate and undeliberate littering by the public. Moreover, the extended retention time and the infiltration of storm water will lead to a reduction in peak pollutant concentrations in the water recipient.

Waste water treatment

Today most waste water in the OSPAR region is treated in municipal waste water treatment plants even though the performance and technology differs substantially in the region. Waste water sources are domestic waste water, storm water, and industrial waste water. The data is very scarce concerning the litter content in the waste water from these different sources. Litter content in industrial waste water depends on the specific activities involved in formation of the water. Litter in domestic sewers can be presumed to be composed of synthetic particles from personal care products and household cleaning products, and fibers from household dust and from washing machine effluents. Particle characteristics like polymer composition, morphology and colour can give important information on their origin. Analyses have shown that polyethylene and polystyrene are particularly common among microplastics particles in waste water. No real effort has been done to connect characteristics of microscopic litter to the source of the waste water.

Conclusions on waste water:

- The efforts made within the OSPAR member states to reduce the discharge of untreated waste water and to include conventional primary and secondary treatment of the municipal waste water would at the same time have a substantial effect in reduction of the marine litter.
- Waste water emerging substances often called micro pollutants are identified as of a major concern today. However, microlitter has so far only been included in few studies of emerging pollutants.
- Waste water treatment plants (WWTPs), with mechanical, biological and chemical treatment of the waste water will based on these studies retain >97% of microlitter $\geq 300 \mu\text{m}$ and generally >80% of litter particles $\geq 20 \mu\text{m}$ in the sewage sludge.
- Inlet grids remove between 5-10% of the suspended solids. Primary treatment removes approximately 30-65%, secondary treatment removes approximately 25% and tertiary treatment removes about 5% of total suspended solids. This treatment efficiency can be used as a proxy also for microlitter, which are included in the total suspended solids, even if some of the microlitter do not settle due to low density.
- Pre-treatment grids/screens may also be applicable in areas with combined sewer systems prone to overflow in order to reduce discharge of large litter (>5 mm).
- To comply with stricter regulations on phosphorus, ultrafiltration (UF) techniques are more widely applied today, which enhance the reduction of suspended solids and thus microlitter to nearly 100%.
- The average investment costs of a disc filter (type of UF), 0,1 MEUR, are double the cost of a coarse grid/screen, but only about one fifth of the cost for a sand filter. The investment costs for advanced technologies such as nanofiltration and reversed osmosis are about 4,4 MEUR and 5,5 MEUR (plant load 100,000 PE).

3 Introduction

3.1 Scope and objective

The scope and the objective of this project was to compile a report containing information of the best available technology (BAT) to reduce litter in the major sources of litter; waste water and storm water, as part of the OSPAR regional action plan against Marine litter, Action 42.

The project aimed to develop a report as a basis for further policy decisions within the OSPAR member states and nationally, primarily in connection with the implementation of the OSPAR RAP on Marine Litter, Action 42 and the Marine Strategy Framework Directive (MSFD) descriptor 10 which concerns marine litter.

Action 42 includes to: *Investigate and promote with appropriate industries the use of Best Available Techniques (BAT) and Best Environmental Practice (BEP) to develop sustainable and cost effective solutions to reducing and preventing domestic waste water and storm water related waste entering the marine environment, including micro particles.*

Although the occurrence of litter in the ocean has been known for many decades, and the problems related to the large and microscopic litter is becoming increasingly well-known through on-going research programmes, the question on how to reduce the load from land is still somewhat in its infancy. This document starts with a general introduction to marine litter and its sources, followed by a chapter on regulation of sources of marine litter, before the role played by storm water and waste water is discussed. Readers interested in storm water including technologies and costs for the reduction of litter are directed to chapter 6 and readers interested in the reductions of litter in waste water to chapter 7.

4 Properties of litter

The combination of litter size, density and shape affects how litter items are transported by wind and water, in which matrix they occur and where they finally end up. These inherent properties also dictate how litter of different sizes and different materials can be sampled from various matrices like water, soil, sediment, air and biota. These different properties are also essential when considering different possible treatment technologies.

4.1 Definition of marine litter-size

A task group of selected experts working on descriptor 10, marine litter, of the MSFD has defined marine litter as “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal

environment” [1]. It also includes materials transported into the marine environment from land. From this definition it is easy to envisage macroscopic litter. However, it is important to emphasize that litter also occurs in the microscopic size (<5 mm).

4.2 Litter shapes and materials

Marine litter includes items of a variety of different sizes, forms and densities. The litter item can occur in its original shape or it can be defragmented into smaller pieces. Litter fragments can have structures such as fibres, flakes and films and be more or less worn by forces of nature.

Litter may consist of a range materials such as plastic, rubber, paper, metal, glass and textile and combinations of these materials [2]. Among them, plastic is considered to be the most persistent and problematic.

Due to their many unique properties (e.g. mouldable, durable, light weight and inexpensive) plastic polymers have been used in products with a wide range of applications for more than half a century. Plastic litter on beaches and in the sea were long been regarded as merely an aesthetic problem. However, with an increased spread of documentation of marine animals being killed after having swallowed or being snared in marine litter, the problem was taken more seriously. The fact that also litter in the microscopic size range could cause harm to the marine ecosystems was however long neglected. An article by Thompson and co-workers, where they presented their findings of microscopic plastic particles in zooplankton samples from the North Atlantic, became an eye-opener also for this side of the problem [3].

Microplastic litter in the environment may either occur as plastic particles that have been originally produced as plastic pellets (“primary microplastics”) or they may be the result of fragmentation of larger plastic items (“secondary microplastics”). The sources to primary microplastics may be e.g. the plastic industries producing plastic pellets used as raw material in other industries, or microplastic particles in personal care and cleaning products. Secondary microplastics can be formed during numerous activities and processes related to construction, maintenance or use of plastic items. An important group of secondary microplastics is also particles formed through fragmentation of plastic litter.

Fragmentation of plastic litter is facilitated by UV radiation from the sun [4]. The UV radiation causes photodegradation and makes the plastic become brittle and fragile, which in turn makes it more susceptible to mechanical forces. This is apparent for plastic litter on beaches where the forces caused by wind, waves and the abrasion of sand grains will be more effective in fragmenting the plastic litter after some time of exposure to sunlight. However, the complete degradation of plastic to CO₂ and other small molecules is a process that can take many decades and even centuries. The UV degradation of plastics is temperature dependent, with higher degradation rates at higher temperatures. Since water has a cooling effect the degradation will be much faster for plastic items on land than for plastic

floating in the water [5]. UV light also decreases rapidly with water depth which means that plastic litter floating on the sea surface is degraded much more rapidly than plastics deeper down in the water column or on the sea floor.

An important fact to take notice of is that unless it is taken care of, all large plastic litter in the environment will eventually disintegrate to smaller plastic fragments and add to the pool of microplastics.

4.3 Environmental effects of marine litter

Marine litter comprises a range of different materials of anthropogenic origin but plastic is often considered to be the most problematic. The harmful effects plastic litter has on marine life depend on the size, shape and polymer composition of the litter items. Entanglement in lost fishing nets or synthetic ropes may lead to seriously reduced quality of life for the trapped individuals, and ultimately to suffocation and starvation. Ingested plastic litter has been detected in numerous species of marine mammals, sea turtles, sea birds, fish and invertebrates [6]. Among the highest prevalence of plastic in marine biota has been found in the northern fulmar (*Fulmar glacialis*) from the North Sea where plastic was found in 95% of 1 295 individuals analysed between 2003 and 2007 [7].

In addition to the mechanical impact many kinds of plastics release toxic compounds to the environment. Some plastic polymers are composed of toxic monomers that may leak out to the surrounding water at normal environmental temperatures. Polystyrene releases the monomer styrene, a possible carcinogenic substance [8], and polycarbonate releases bisphenol A, known to have estrogenic properties [9]. All plastics also contain additives to obtain certain desirable qualities or functions and many of these are potential contaminants if released into the environment. Examples of this are plasticisers like phthalates and flame retardants like the brominated diphenyl ethers. Toxic additives may leach out from plastic litter on beaches and in the water, and plastics swallowed by marine biota may release additives into the gastro-intestinal tracts of the animals [10].

Like all organic matter plastics adsorb hydrophobic organic contaminants from the surrounding water to its surface, and if the plastic litter is moved around with wind, waves and sea currents, this may be an efficient transportation also of the associated contaminants [11]. The relative importance of plastics as vectors for other contaminants in the sea is however debated. Organic contaminants seem to partition between water and plastics in a way similar to how they partition between water and all other natural organic material. The total fraction of contaminants adsorbed to plastics in the sea today could therefore be presumed to be very low compared to the fraction adsorbed to living organisms or dead organic material [12]. Still, since plastic litter is much more long-lived than natural organic matter it cannot be excluded that its role as a vector could be of some importance. There are also certain environments where the plastic litter is exposed to particularly high concentrations of organic contaminants and where the vector function may be more significant. An example of such an environment is municipal waste water, which

contains both microplastic particles from a variety of upstream sources, and elevated concentrations of numerous organic compounds like e.g. nonylphenol, phthalates and PCB [13]. When these plastic particles are released with effluent waste water they may have pollutant concentrations considerably higher than the natural particles in the receiving water.

4.4 Pathways and quantities of marine litter in the OSPAR region

Most litter found in the North Sea and the Baltic Sea is assumed to derive from within the two regions rather than from the surrounding sea areas. For microlitter this has been tested with a global oceanic hydrodynamic model, where virtual microparticles were introduced in the flow field of known surface currents [14]. According to the model 98% of the microparticles found in the North Sea came from within the area, and for the Baltic Sea this figure amounted to almost 100%.

It is frequently stated that 80% of the marine litter is of land-based origin and although there is limited data to support the exact figure, land-based sources certainly are dominating over the sea-based ones. And as a result of concerted actions to reduce litter from the shipping industry by marine litter conventions, the dominance of land-based sources could be expected to have increased over the past 25 years. A recent estimate of the amount of plastic entering the ocean from land has been presented which ranges from 4.8 to 12.7 million tons in 2010 [15].

In the UNEP report “Marine litter: a global challenge” (2009) discharge from storm water drains and untreated municipal sewerage are depicted as major land-based pathways for litter to the marine environment [16]. Litter from land may also find its way to the sea via transportation with rivers and other water ways, through direct run off from land and by deposition from the air.

Storm water is believed to play a major role in the transportation of litter from the source where it is emitted to the water recipients. Still, there is an almost complete lack of data on litter and microlitter in storm water.

Storm water is formed as precipitation flows over impervious and pervious surfaces. This leads to a wash off of litter from the surfaces and further transport of the litter in the storm water drainage systems. The interval between precipitation events, along with their intensity and durability, leads to variations in wash off efficiency, in litter concentrations in the initial runoff (i.e. “first flush”) and in the litter load reaching the storm water. Storm water is either drained into the sewage system and treated in a waste water treatment plant (“combined system”), or transported separately to the recipient with or without storm water treatment (“separate sewer systems”).

Traffic dust, which contains abrasions from tires, breaks, road pavement etc. has been identified as one of the most important sources of microlitter particles that is expected to be transported with storm water [17, 18]. The emitted traffic dust particles may be deposited on the roads and eventually be rinsed off by rainwater, they may be deposited in the close vicinity of the road or they may be dispersed in the atmosphere for deposition away from the road. In areas with a sewer system the rinsed off water bound particles will end up there. Based on data from a study by Sörme and Lagerqvist (2002) on traffic dust in the city of Stockholm, Lassen et al. (2015) estimated that in areas with a sewerage system 30-50% of the emitted traffic dust particles could be expected to end up there [19, 20]. The particle size seems to be the most important factor determining whether the particles will be emitted to the air or stay on the ground. In the case of the road dust particles it has been shown that abrasion particles from break lining generally are relatively small ($<10\ \mu\text{m}$) and hence more prone to be airborne than e.g. the larger particles derived from wear of tires [19].

Due to limited data it is very difficult to estimate the quantities of litter in storm water. It is however found that litter concentrations are elevated in water in urban areas with paved surfaces where the run off from land is facilitated. In the harbour of Malmö concentrations of microplastics $\geq 300\ \mu\text{m}$ in surface water amounted to around 50 particles per m^3 compared to levels between 0.08 and 0.69 per m^3 outside the harbour area [21]. In the harbour of Gothenburg sampling of microplastics $\geq 300\ \mu\text{m}$ was done both during a long period of dry weather and during a period of rain. The microplastic concentration was found to be considerably higher in connection to rain, on average 2.9 microplastic particles per m^3 compared to 0.9 microplastics per m^3 lower during the dry period [22]. The extra load of plastic particles most likely had reached the water in the harbour via run-off from land.

In northern Europe the dumping of snow that has been collected in urban environments is another important transport pathway for litter to the sea. This snow will contain not only litter of all sizes but also toxic emission particles from car exhausts and from heating of houses. As snow is dumped into the water it will cause a dramatic exposure peak of all these harmful particles and compounds to the aquatic organism in the area. Dumping of snow in water recipients is therefore banned in many countries.

Untreated and treated municipal waste water can contribute with substantial amounts of litter to the aquatic environment. Studies carried out in Sweden, Finland, Norway and Germany have shown that in waste water treatment plants (WWTPs) with mechanical, chemical and biological treatment of the waste water the vast majority of the litter particles in the influent water are retained in the sewage sludge and will therefore not be released with the effluent water [23-26]. Still the input of microlitter to the recipient water via discharge of treated waste

water was found to be substantial. Different cut off size were used in the different studies, and the observed concentrations of microplastics $\geq 300 \mu\text{m}$ were around 10 - 40 per m^3 [22], for particles $\geq 20 \mu\text{m}$ 2 600 – 5 600 particles per m^3 [25] and for particles $\geq 10 \mu\text{m}$ 86-13 659 per m^3 [26]. In those studies where the flow rate of the waste water was known it was possible to calculate the total load of microplastics to the recipient water. The load is of course closely connected both to how efficiently the microlitter particles are retained in the WWTP and also to the number of people connected to the plant. In Table 1 is presented the annual load of microplastics from WWTPs of different size in some European countries. All WWTPs represented in the table have mechanical, biological and chemical treatment of the waste water except the Icelandic WWTPs which only were equipped with a mechanical treatment step.

Table 1 - Number of microplastics in the treated waste water that will be discharged to the recipient. All WWTPs but the Icelandic have mechanical, biological and chemical treatment of the waste water, whereas Iceland has only mechanical treatment. PE= Person Equivalent

Microplastics in effluent waste water	
number of particles per year	
3 Swedish WWTPs [25] 12 000 – 750 000 PE	$0.12 \cdot 10^9 - 4.5 \cdot 10^9$ (particles $\geq 300 \mu\text{m}$)
3 Swedish WWTPs [25] 12 000 – 750 000 PE	$0.1 \cdot 10^{11} - 2.5 \cdot 10^{11}$ (particles $\geq 20 \mu\text{m}$)
Norwegian WWTPs [23] 85 000 – 700 000 PE	$0.22 \cdot 10^9 - 3.2 \cdot 10^{11}$ (particles $\geq 300 \mu\text{m}$)
Norwegian WWTPs [23] 85 000 – 700 000 PE	$25.5 \cdot 10^9 - 309 \cdot 10^9$ (particles $\geq 20 \mu\text{m}$)
Finnish WWTPs [22] 40 500 – 800 000 PE	$0.12 \cdot 10^9 - 4.1 \cdot 10^9$ (particles $\geq 300 \mu\text{m}$)
Icelandic WWTPs [22] 26 000 – 97 000 PE	$19.5 \cdot 10^9 - 55.6 \cdot 10^9$ (particles $\geq 300 \mu\text{m}$)
German WWTPs [26] 7 000 – 210 000 PE	$0.093 \cdot 10^9 - 8.2 \cdot 10^9$ (particles $\geq 10 \mu\text{m}$)

An important group of microplastics reaching the aquatic environment via waste water effluents is the plastic microbeads used in personal care products (PCPs). It was estimated that the total volume of microbeads used in liquid soaps in the countries within the North Sea catchment area in 2012 amounted to 2 300 tonnes per year [27]. Liquid soaps are considered to constitute the largest category of PCPs, which makes them interesting when studying the fate of microbeads in the environment. It should however be emphasized that there are also several other categories of PCPs that contain plastic microbeads.

To estimate the load of microbeads from liquid soap in waste water discharged in the North Sea area, information is needed on how the waste water is treated in these countries. A rough estimate gives that between 80 and 100% of the populations in the North Sea states are connected to urban WWTPs and roughly between 30 and 100% of the WWTPs in these countries are equipped with tertiary treatment of the waste water [28]. There still are WWTPs with no treatment of the waste water among the North Sea states, this is the case for around 5% of the Norwegian plants and slightly below 20% of the Belgian ones. There is no available information on the capacity of WWTPs from other European countries but those mentioned earlier (Sweden, Norway, Finland, Germany and Iceland) to retain microplastics in sewage sludge. However, since the plants with tertiary treatment were found to retain more than 97% of the microplastics $\geq 300 \mu\text{m}$, the average value for all North Sea countries should be somewhat lower. The average size of microbeads in liquid soap was around $450 \mu\text{m}$ so the retention found for particles $\geq 300 \mu\text{m}$ should be valid also for them. A very rough guess would be that an average of around 75% of liquid soap microbeads should be retained in the WWTPs of the North Sea countries, which should give a discharge of 575 tons per year of these PCP microbeads via the waste water to the receiving water in this area.

A more detailed description of the fate of microlitter and microplastics in WWTPs is given in chapter 7.

Rivers may be efficient pathways for litter to ocean from a whole catchment area. There are still but a limited number of studies on the amount of microplastics reaching the North Sea via input from rivers. In a study of the Rhine, which is the largest river in the region, the average concentration in surface water was found to be $\sim 890\,000$ microplastics $\geq 300 \mu\text{m}$ per km^2 , with concentration peaks of 3.9 million microplastics per km^2 [29]. This was estimated to correspond to an average of 17 microplastics $\geq 300 \mu\text{m}$ per m^3 . The concentration was high compared to microplastic data reported from the Seine in France (0.3-0.5 microplastics $\geq 330 \mu\text{m}$ per m^3 , and 3 -108 microplastics $\geq 80 \mu\text{m}$ per m^3) [30] and Göta älv in Sweden (0.9 – 2.9 microplastics $\geq 300 \mu\text{m}$ per m^3) [22]. When using the field data on microplastic concentrations in the Rhine to estimate the input of microplastics to the North Sea it was found to be around 190 million microplastics $\geq 300 \mu\text{m}$ per day [29]. To convert the number of plastic particles into a weight it was assumed that the average particle was spherical, with a diameter of $1\,000 \mu\text{m}$ and a density of $1 \text{ kg}/\text{dm}^3$. The Rhine would hence discharge $\sim 100 \text{ kg}$ of microplastics per day, or 36 tons per year to the North Sea. It was however pointed out by Mani et.al. that the figures for the River Rhine transport are probably an underestimation of the true contribution since the calculation only included microplastics in the surface water of the river.

4.5 Sources of litter and litter categories in storm water

Sources producing litter of different sizes that risk ending up in the storm water are shown in figure 1. The sources are described in more detail below. A series of reports on the national sources for microplastics to the environment, including the sources to microplastics found in storm water, have been presented in Norway, Denmark, Germany and Sweden [17, 18, 20, 31].

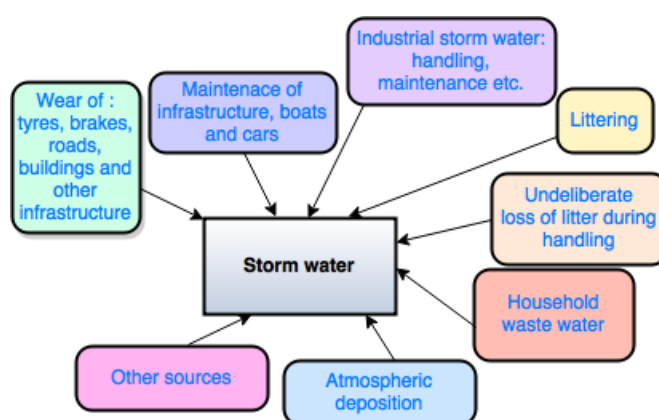


Figure 1. Sources of litter to storm water.

4.5.1 Deliberate and undeliberate littering

Littering mainly encompasses large litter items clearly visible on the ground. Large litter may however be fragmented into smaller particles through the combination of UV-light and wear from vehicles, pedestrians, waves etc. The litter may have been disposed of intentionally but may also have blown away with the wind from open or full trash bins, recycling stations, waste deposit plants and litter transport vehicles. *Litter* includes items made of plastic, paper, well, glass and metal, and consist of for example plastic bags and bottles, glass bottles, food containers, cigarette butts etc.

4.5.2 Wear caused by traffic

Traffic gives rise to microscopic litter mainly from tire wear, road abrasion (asphalt and road marking) and break wear. The occurrence of micro particles originating from traffic has attained large concern, but they have not generally been depicted as litter. The particle sizes that so far have been of major interest from a research perspective and a societal perspective is the very small airborne particle fraction with a diameter of less than 10 μm (PM_{10}) that can enter the human respiratory

system and cause negative health effects. Therefore the concentration of particles less than 2.5 μm wide ($\text{PM}_{2.5}$) and PM_{10} is often regulated. As there is a convention on Long-Range Transboundary Air Pollution PM_{10} emissions from different sources are surveyed and reported. Particles in this size range are also produced by traffic through both combustion and wear from tires, road and brakes. The fraction of particles that can be airborne are between a few nanometres to 100 micrometres [39].

Although the original wear comes from different sources, the particles found in storm water can be made up of a mixture of wear from tires and breaks [40]. Likewise, it has been found that tire particles may contain fragments from the pavement [41]. Thus, it is not enough to make toxicological studies on for example pure tire material to estimate toxicology of road dust particles. It has been estimated that the loading of total suspended solids (TSS) on motorways and major roads can be between 815-6 289 kg/ha/year (based on European data) [42], which makes it very important to analyse how much of the TSS that consists of anthropogenic particles and how much consists of natural dust.

Three recent Nordic reviews of sources of microlitter have pointed out road wear as being one of the most important [17, 18, 20]. Car tires are made up of numerous different rubber compounds, many types of carbon black, fillers like clay and silica, and chemicals, minerals added to allow or accelerate vulcanization [18]. About 35% of the tread part of the tire consists of rubber polymers and approximately 20% of the weight of a tire wears away as microplastic particles during the life of a wheel [43]. Rubber emissions from tires in Sweden have been evaluated in a study for two vehicle classes; cars where the wear is supposed to be 0.05 g rubber per vehicle and kilometer, and buses where the wear is 0.7 g rubber per vehicle and kilometre.

The Swedish emissions to rubber dust from wear of tires were estimated to 13 000 tons per year, the Danish emissions to 4 200 – 6 600 tons, the Norwegian emissions to 4 500 tons and emissions in the UK to 53 000 tons per year [17, 20, 39]

The total abrasion of asphalt is estimated to 110 000 tons per year in Sweden [44]. Bitumen is the binder in asphalt. In the normal asphalt the binder content is typically about 5-6% by weight corresponding to about 10% by volume [45]. In order to improve the properties (viscosity) of asphalt, polymers are added to some bitumen. The emissions of polymers from the Swedish road network were estimated to 15 tons per year, assuming that the concentration of polymers is the same in road wear as in new asphalt [18].

Another source of microplastics from roads is abrasion of road marking. These are partly thermoplastic, partly polymer paints. The content of road marking is mainly fillers but the typical thermoplastic elastomer content is about 1-5% [17]. Estimations made for Denmark indicate that 110–690 tonnes of thermoplastic road marking material is emitted as microplastic particles due to wear per year [20]. The report used the elastomer content of 0.5-2% according to Danish manufacturers and abrasion factor of road marking of 15-43%, and estimated the microplastic

elastomer emissions are 4-50 tons per year for Denmark. Calculating on Denmark road length year 2010, which was 73 574 km, emission factors thus became:

- 0.05-0.68 kg per year and kilometer road.

The Swedish emissions from the total yearly consumption of road marking using Norwegian emission data and based on Sweden road length, 579 567 km, resulted in the following emission factor:

- 0.87 kg per year and kilometer road.

The emission of microplastic elastomer in Sweden would hence be 504 tons per year.

An important aspect when studying the fate of the various components of traffic related particles is that of densities. Exhaust particles have a density of 0.32–1.2 g/cm³ and tire particles a density of 1.2-1.3 g/cm³ [46]. Road dust, consisting of many different particle types, may have a density of 2.14–2.54 g/cm³ depending on particle size [47]. Thus a variety of particle sizes and particle densities need to be taken into regard when trying to reduce microlitter concentrations.

4.5.3 Maintenance of infrastructure, boats and cars

Cleaning of constructions, paved surfaces etc. can be done by using high and low water pressure washing as well as blasting with particles of different materials. Infrastructures such as roads, tunnels, bridges, roofs and facades are regularly cleaned which introduces additional wear on these surfaces and the possible creation of microlitter. In Norway building repair was estimated to create 270 tons of microplastic pollution per year, but only part of this will end up in storm water [17]. The Swedish total emission of microplastics from protective coatings and decorative paint were estimated to 128-251 tons per year [18]. Activities like cutting and fitting of plastic objects, such as pipes for different uses, may also produce microlitter. Some of the microlitter from these different sources might eventually end up in the storm water.

4.5.4 Industrial storm water

Industrial storm water may contain particles created during outdoor washing and blasting of cars, ships and infrastructure. Outdoor handling of products or raw materials consisting of micro plastic particles may lead to accidental spills and thereby also to possible releases of microplastics to the storm water system.

Information on emissions regarding storm water load of industrial plastic pellets production and handling is based on the report by Magnusson et al (2016). Historically, plastic pellets have been a major constituent of marine microplastics. There has been evidence of considerable point source inputs of plastic pellets or powders near to plastic processing plants [48]. However, over the last decades the amounts of plastic pellets have decreased by approximately 75% [49, 50]. In spite of the decreasing trend, emissions of primary plastic pellets still continues, evident for example by the very high water concentration of pellets in an industrial harbour outside a large manufacturing plant in Sweden where peak values of 102 000 per m³ were detected [51].

Two emission factors used for estimating the loss of plastic pellets during handling was found in the literature, one based on measured losses in Danish plastic converting facilities and used to quantify losses in Denmark [20] and the other developed by USEPA and used to quantify Norwegian losses [17]. A safety span was applied and the average emissions were estimated to be within a range of 0.0005%, approximately half of the emission from the highest reporting conversion facility and 0.01%, ten times the emission at the highest reported facility (Table 2).

Table 2 Emission factors of loss from plastic pellets production and handling, based on [17, 18, 20].

Plastic pellets industry	Emission factor (% loss of total production of plastics)
Production	0.04%
Handling and transport	0.0005%-0.01%

4.5.5 Atmospheric deposition

Atmospheric deposition or fallout can be a source of microparticles in storm water. Specifically fibres have the possibility to transport with wind and fallout at other sites. The total atmospheric fallout in Paris has been determined to an average of 118 particles per day per m² with a composition of 90% fibers[30].

4.5.1 Other sources

Artificial turfs commonly used for soccer fields have been pointed out as another large source of microplastics [18]. In Sweden the loss of plastic granulate was estimated to 2 300-3 900 tons per year based on e.g. manufacturers' recommendations on yearly refill of material. In Denmark a similar estimation showed a total release of infill granulates of 380-640 tons per year [20]. This source may however be overestimated since not all soccer fields are managed according to recommendations. Geographic location is likely to have large impact on the loss of granulates, while most losses seems to take place during winter conditions, due to snow clearance.

Vegetation and sand does not count as litter, but these substances enter the storm water systems and may constitute a large part of what will be collected in a litter trap.

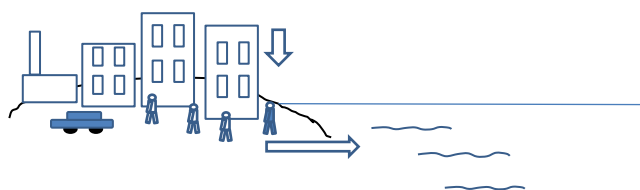


Figure 2. Sources for micro litter emerge wherever wear is occurring or enhanced.

4.6 Sources of litter and litter categories in waste water

The amount and composition of litter reaching the waste water treatment plants (WWTPs) is highly dependent on the origin of the incoming water. A division of different kinds of waste water is presented in the Urban Waste water Treatment Directive (91/271/EEC):

- *Urban waste water* means domestic waste water or the mixture of domestic waste water with industrial waste water and/or run-off rain water (thus storm water).
- *Domestic waste water* means waste water from residential settlements and services which originates predominantly from the human metabolism and from household activities.
- *Industrial waste water* means any waste water which is discharged from premises used for carrying on any trade or industry, other than domestic waste water and run-off rain water.

The ratio between urban, domestic and industrial waste water in WWTP incoming water differ between the OSPAR member states. It is therefore likely to be differences also in the composition and abundance of microlitter in the waste water. Storm water is likely to contain more litter than e.g. waste water from households, whereas the litter content in industrial waste water depends on the specific activities involved in formation of the water. Litter in domestic waste water is probably the most easy to predict and can be presumed to contain objects thrown into toilets, synthetic particles in personal care products and household cleaning products, fibers from household dust and from washing machine effluents [17, 52].

Particle characteristics like polymer composition, morphology and colour can give important information on their origin. Although there is some information on both the number and composition of litter particles in waste water, no real efforts have been made to link individual particles to specific sources. In practice this means that statements of sources for litter in waste water still must be considered as speculative, and that it is not yet possible to assess the actual importance of each specific source.

Studies on litter in WWTPs have mainly focused on the microlitter fraction i.e. particles ≤ 5 mm [24, 25, 53, 54]. It has been found that in WWTPs equipped with mechanical, biological and chemical treatment the vast majority of the litter particles are retained in the sewage sludge. The retention efficiency is $> \sim 97\%$ for litter particles ≥ 300 μm , and generally around $> \sim 80\%$ for particles ≥ 20 μm [22, 25]. Measurements in a WWTP with only mechanical treatment showed that particle concentrations in influent and effluent water were in the same range, which means that there had been no retention of microlitter in the plant [22].

5 Regulation of sources of marine litter

There is a broad range of international and EU environmental legislations in the area of waste management, urban waste water treatment and regulations concerning dumping from ships. Waste management legislation should be seen in the broader context of enhanced resource efficiency, now a key cross-cutting policy goal. The EU's resource efficiency policy should have a beneficial upstream impact by influencing the use and design of plastic products and particularly of packaging. In terms of legislation dealing with the impacts of marine litter on the coastal and marine environment, the EU Integrated Maritime Policy (IMP) and the Marine Strategy Framework Directive as its environmental pillar, address the development of sea-related activities in a sustainable manner.

The EU has also adopted a set of rules to reinforce maritime safety and help prevent pollution from ships including:

- the Ship-source Pollution Directive (2009/123/EC);
- the Port Reception Facilities Directive (2000/59/EC).

The EU Marine Strategy Framework Directive addresses program of measures for marine litter (descriptor 10).

The OSPAR member states have adopted a Regional Action Plan against Marine Litter, Action 42, and the final version of the Ministerial declaration of OSPAR 2010 states: 'We note that quantities of litter in many areas of the North-East Atlantic are unacceptable, and therefore we will continue to develop reduction measures and targets, taking into consideration an ambitious target resulting in a reduction in 2020 [55].

5.1 Conventions regulating marine littering

Earlier, deliberate dumping at sea, that is disposal of wastes at sea as a way of waste management, was common and also legal. This problem was internationally addressed by the London Convention and the regional Oslo Convention regulating dumping in the North East Atlantic that was signed in 1972. Throughout the years more and more substances and items have been prohibited from dumping at sea by the convention. Important sources of plastics in the oceans summarised in 1987 were: ships, litter carried to the sea by rivers and municipal sewage systems, and litter left at beaches [56]. One of these sources, vessels, was and is in focus in the MARPOL Convention which regulates pollution at sea. Annex V specifically concerns discharge of waste at sea and was adopted in 1988.

5.2 Treatment requirements of waste water within the EU

European and most OSPAR countries are regulated by the Urban Waste water Treatment Directive (91/271/EEC) from 1991 which has a fundamental impact on the design and objective of European waste water treatment plants. The aim of the Directive is to protect the environment from the negative effects that discharge of untreated urban waste water bears with it. In the directive urban waste water means domestic waste water or the mixture of domestic waste water with industrial waste water and/or run off rain water. The specific substances that are regulated within the directive are organic load and nutrients. The regulated discharge concentrations alternatively reduction levels are coupled to the number of persons (population equivalent; PE) within an area (called an agglomeration in the directive) from which waste water is discharged, the type of recipient to which the treated waste water is released and the classification of the recipient. The terminology of the different treatment levels of waste water that are mentioned within the directive are: primary treatment, secondary treatment, appropriate treatment and more stringent treatment. These treatment levels are not tightly coupled to specific techniques but rather to the quality of the discharged water or the degree of pollutant reduction.

According to the directive, primary treatment is a physical and/or chemical process that reduces the biological oxygen demand (BOD₅) of the incoming waste water by at least 20% before discharge and total suspended solids by at least 50%. Secondary treatment normally involves biological treatment with secondary settlement or other processes such that the requirements of Table 1 of Annex 1 in the directive are fulfilled. Table 1 in the directive regulates concentrations, alternatively percent of reduction, for biochemical oxygen demand, chemical oxygen demand and total suspended solids. The need for secondary treatment is applicable for agglomerations with > 2 000 PE if the water is released to fresh waters or estuaries and applicable for agglomerations with > 10 000 PE when the water is discharged to coastal waters. When treated waste water from agglomerations with >10 000 PE is discharged into sensitive areas (sensitive to eutrophication) more stringent treatments are needed to fulfil the requirements of Table 2 of Annex 1 in the directive. This table presents concentrations alternatively percent reduction levels for total phosphorus and total nitrogen for discharged waste water. One or both of the nutrient variables may be applicable depending on the situation.

A brief overview of the classifications within the directive is presented below (see Table 3).

Table 3. Brief overview of treatment classifications within the Urban Waste water Directive with input from the Waterbase-UWWTD and the report “Waste water treatment in the United Kingdom – 2012” published by the Department for environment, food and rural affairs in London [57] .

Treatment	Process/technique	Receiving water classification	Receiving water type	Person equivalents within the agglomeration
Appropriate	From no treatment to tertiary treatment as long as quality objectives and provisions of the UWWTD and other Directives are met*		Freshwater, Estuarine	<2 000
			Coastal	< 10 000
Primary	Settlement of suspended solids	Less sensitive area	Estuarine	2 000–10 000
		Less sensitive area	Coastal	> 10 000
Secondary	Biological treatment	Normal area	Freshwater, Estuarine	>2 000
		Normal area	Coastal	>10 000
More stringent treatment (Tertiary)	Various treatments to meet emission or water quality standards	Sensitive areas**	Freshwater, Estuarine, Coastal	>10 000**

*Article 2.9 of the Directive concerning urban waste water treatment (91/271/EEC) (UWWTD)

** Sensitive areas fall into three categories: a) eutrophic or risk of becoming eutrophic, b) drinking water source and c) sensitive areas according to other directives. Areas regarded as eutrophic or risk of being eutrophic has to follow table 2 of Annex 1 of the directive to reduce nitrogen and/or phosphorus. Sensitive areas according to other directives do not have a designated threshold regarding number of person equivalents.

Emission- and reduction levels described above have to be followed for discharged water to be compliant with the directive. Consequently stricter applications are thus beyond the requirements of the UWWT Directive. Each member state may however set stricter national requirements on the discharge of waste water. The term “more stringent treatment” often called tertiary treatment which is required for discharge to sensitive areas means the reduction of phosphorous and/or nitrogen for discharge to eutrophic areas [58]. For discharge to sensitive areas used as drinking water sources nitrate has to be removed and for discharge to waters classified as sensitive areas according to other Directives tertiary treatment may consist of the removal of for example pathogens or toxic substances [58].

6 Storm water management

Storm water arises in all urban areas and therefore the history of storm water drainage systems is as old as the history of human settlement into villages [59]. The structure and intention of today's systems and terminology of the technologies vary within and among countries, and over time [60].

Storm water occurs when precipitation such as rain or melting snow runs off from impervious or semi-impervious surfaces. Large volumes of water can rapidly arise with heavy rain in urban areas and cause flooding and transport of litter. Due to climate change, precipitation patterns are changing and flooding caused by storm water overflows are predicted to increase in northern Europe and North-western Europe [61].

European cities in general have a large proportion of combined sewage drainage systems, but differences are large in-between countries and cities. In Sweden only 12% of the total sewer system consists of combined systems [62]. In the combined systems both storm water and waste water is transported and treated at the waste water treatment plant (WWTP). In this way storm water is treated too, however, the combined systems are more sensitive to weather conditions and changes in urban land use. More paved areas lead to faster hydrologic response and higher peak flow. The storm water is also colder than the domestic waste water and contains pollutants that risk impairing the treatment process and deteriorating the sludge quality.

If the sewer system lack capacity to managing all the waste water controlled or uncontrolled overflows will take place meaning that untreated or moderately treated waste water is released into the recipients increasing litter load on the environment.

6.1 Aims for storm water management - a historic development

There are many strategies of storm water management due to diversity of, for example, historical choices of infrastructure, degree of precipitation, winter conditions, number of inhabitants, industrial categories and the character and sensitivity of the surrounding environment.

6.1.1 From water volume removal to pollution retention

Initially, the main purpose with storm water management was to remove the water from urbanised areas and roads as fast as possible. However, as it was realised that sudden peak flows of water could create problems such as erosion and high loads of sediments into recipients the management trend in the 1970's shifted in order to detain water flow and to increase infiltration [63]. Already in the 1960's it was known that storm water could contain high levels of both suspended solids and nutrients and could thus pose a risk of harming receiving recipients [64]. However,

it was not until the 1980's and 1990's that management of storm water came to take the polluting aspects more into account [63]. In the UK sedimentation chambers, storage tanks and dynamic separators were installed to separate pollutants but also to increase retention [65]. New ways to reduce the pollutants were also explored and in the 80's the use of vegetation such as reed to treat storm water was tested in many areas. Subsequently the use of vegetation was also introduced to treat storm water from roads to enhance sedimentation, pursue bioaccumulation of pollutants and to trap heavy metals within the sediment [66, 67].

6.1.2 Green infrastructure development

The view on how to manage storm water has developed with the evolution of drainage management system concepts [60]. One of these systems is low impact development (LID) also called sustainable drainage systems (SuDs), which has been used in North America and New Zealand since the 90's [60]. Originally the aim was to attain a natural hydrology with an onsite design using green roofs and swales instead of end-of-pipe solutions. In the late 90's the concept evolved to include any systems that treated storm water on a smaller scale. Presently the concept of green infrastructure (GI), which implies the extended use of vegetation in green roofs and raingardens as well as permeable surfaces to manage storm water is the modern term for LID [60].

6.1.3 Source control storm water management

Originally, source control was described as a way to prevent pollution with the help of site design and a deliberate choice of building material. Later the concept has also been presented and used as a concept where specific storm water treatments are applied close to the source in order to treat pollution [60].

6.1.4 Storm water management development towards blue and green values in the urban landscape

Other management concepts were developed in the 1990's: water sensitive urban design, integrated urban water management, water sensitive areas as well as green infrastructure, which emanated in different countries and disciplines [60]. Today there is an emerging aim to implement and expand the concept of storm water management where the system is intended to enhance the urban environment both functional, visually and experientially by adding blue and green areas. Green areas enhance the urban climate by reducing the heat island effect and improve biodiversity. Blue areas management systems that mimic the natural water cycle thus create cultural ecosystem services in urban areas. Systems incorporating plants and water structures as ponds and wetlands also provide refuge for pollinators and increase local biodiversity which is additional societal wishes and ecosystem services that are highly regarded.

6.2 Storm water litter reduction – technologies and costs

There are only few scientific studies published on techniques to reduce litter of any size in storm water and also very limited information on the cost for investment and maintenance of these facilities. Many technologies are primarily designed to reduce large litter but may nevertheless have an effect on microlitter as macro litter is a source of microlitter. No information has been found on concentration of microlitter in storm water or techniques to reduce microscopic litter in storm water. The identified technologies for storm water management that may lead to a reduction in litter concentrations are presented in the Table 4. Policy- and information measures as means of reducing litter in storm water are likely to be cost-effective. This was however beyond the scope of this project and has not been investigated.

It is important to underline that particle size distributions seldom are analysed for in tests and evaluations of storm water treatment systems. This is probably one of the reasons why the performance of different systems varies among studies as the size and the density of the particles decides settlement velocity and sedimentation is the main treatment mechanism for many systems.

The most commonly used storm water treatment technology is wet-basin ponds. It is evaluated to give relatively high reduction efficiency with regard to total suspended solids, more than 65 % reduction [68]. Wet basin ponds are used in all types of storm water producing environments; roads, urban environment, industrial areas, and recreational environment. However, the wet basin ponds are poor on reducing dissolved and colloidal pollutants. Large litter and microlitter with a density $>1 \text{ kg/dm}^3$ are therefore likely to be retained efficiently in wet ponds, while microlitter with lower density is likely to pass through ponds and other detention systems.

Table 4. Summary of technologies, their efficiency (estimation done in the present study) and cost for reducing litter in storm water.

Technology	Device	Reference	Efficiency Low=1 High=5	Description	Maintenance	Cost	Comments
Up-stream	Litter bins	[69-74]	3		Important that the bins are not full.	According to a study in Cape Town the most cost efficient measure to minimize litter ending up in storm water. 5 Rand / kg litter (2001).	Cannot be the only measure.
Up-stream	Street sweepers	[72]	3	Cost efficient upstream solution minimizing litter ending up in storm water.		After litter bins the most cost effective technology. Estimated cost in Cape Town 12 Rand/kg litter (2001).	

Screens	Screens and racks	[75] [76] [77]	2	Simple screens can be placed at the inlet, more complicated structures are placed in-line and mesh baskets and racks are placed at the outlet	Trash removal differs among devices. At the inlet trash is removed by street sweeping. In-line and outlet devices require vacuum truck.	Inlet screen start at 400 USD, gross solid inline device 50 000-300 000 USD and outlet device about 8 000 USD	Inlet screen is cheap but may cause flooding. Needs regular maintenance. . In-line device can have very high capital and installation cost. End-of pipe screens can be clogged.
Filter	Catch basin inserts	[74]	2	Baskets, trays, screens placed inside inlet or at outlet of catch basin.	Cleaning with vacuum trucks takes 30-60 minutes per insert.	200 USD- 6 500 USD /unit.	Very few tests seem to have been designed to test the performance regarding litter removal. Two studies showed that the inserts may cause problems with flooding and re-suspension of fine particles. Maintenance can be an important drawback.
Filter	Netting devices	[74]	2	Disposable nylon nets place in-line or at end-of pipe.	Nets are removed with a crane.	Planning and construction 75 000 – 300 000 USD. Labour requirement differ.	Effectiveness range between 86-97%. As nets full with trash is not very aesthetic the nets should not be placed were they are visible.

Booms	Litter booms	[74]	1	Floating booms with hanging curtains	Trash is removed with a boom truck or with a skimmer vessel	Cost per site 48 000 USD (2003) to 240 000 USD (1999).	Performance is not high while it only traps floating litter and the price can be high.
Sedimentation	Detention basin. Sedimentation removes larger particles and floating litter is captured.	[78, 79]	3	Captures and detains water for typically 48 hours. Sedimentation removes larger particles and floating litter is captured. Size typically 2-3% of the contributing drainage area.	Medium	300 SEK/m ³	Regular inspection and removal of litter and sediment is needed.
Sedimentation	Wet basin/pond.	[78, 79]	4	This construction holds a permanent pool of water and often contains vegetation that helps in removal of pollutants.	Medium		
Sedimentation	Constructed wetland	[78, 79]	4	A land area that is saturated with water, either permanently or seasonally with characteristic vegetation of aquatic plants.	Medium		

Infiltration	Sand filter	[78, 79]	5	High treatment efficiency but low capacity. Water filtrates through sand, geotextile and gravel. The basins are constructed by digging out soil.	Maintenance requires sediment removal and filter media replacement.	No exact price is given but it is stated to be larger than for a detention dam.	
Infiltration	Infiltration basin or trench	[78, 79]	5	This system detains storm water until it percolates into the groundwater. Pollutants are removed by infiltration and adsorption to the soil.	Litter and sediment has to be inspected and removed.	Cheaper than sand filter, while in-situ soil is used for infiltration.	If the water is clearly polluted and the groundwater is of high value restrictions should be applicable.
Flow control	Dry weather flow diversion	[79]	5	During dry weather, flow is directed to the sanitary sewer system, during wet weather it is closed.			Drawback that the sludge quality is reduced due to metals and other pollutants in storm water.
Hydrodynamic	Hydro-dynamic separators	[79]	4	A device which divides trash from the water into a containment chamber.	Trash is removed with vacuum truck.	Capital costs 4 000 to 300 000 USD depending on size.	The systems can be very effective but draw is back is the high cost.

6.2.1 Storm water microlitter treatment and effluent

As studies conducted on storm water seldom include microscopic litter this variable is not possible to retrieve from databases such as the International Storm water BMP Database (www.bmpdatabase.org) or the Swedish Storm water Database StormTac (www.stormtac.com). However total suspended solids is very often measured and reported in storm water analyses and consists of particles retained on a filter with a pore size 0.45–2 µm (size varies among studies). Some of these particles have an anthropogenic origin and therefore the reduction of total suspended solids should to some degree also indicate a predicted reduction of microplastics litter.

There are no limit- or guidance values given for pollutants in storm water in any EU directive or national legislation in the OSPAR countries. According to the EU Water Framework Directive ecological status in waters should however not deteriorate due to emissions from pollution sources including storm water. In the storm water strategy for Stockholm there are suggested guidance values for storm water (annual mean concentrations). The guidance value for effluent suspended solids concentration in storm water to the sea is set to 75 mg/L not to cause negative effects on the marine environment. This could also be used as an indication of when and to what degree litter concentration in storm water should be treated.

In Table 5 is presented a number of treatment technologies for suspended solids together with the expected treatment efficiency. This could be a useful tool and a first approximation also when considering different treatment technologies to reduce microlitter content in storm water.

Table 5. General reduction efficiency (%) for suspended solids in different types of storm water treatment facilities (StormTac, v. 2014-05), [78].

Facility	Treatment efficiency [%] suspended solids
Constructed wetland	75
Infiltration trench	90
Open ditch, road ditch	70
Retention basins	75
Sand filter	75
Wet pond	80

6.3 Emerging technologies for storm water management and potential for litter removal

In traditional storm water treatment like wet ponds, the dissolved and colloidal bound pollutants are as a general rule only poorly treated. These fractions are however most mobile in the aquatic environment and also most easily bio-accumulated. New and emerging technologies for storm water treatment are therefore mainly focusing on these substances.

In a Danish study three different advanced storm water treatment facilities were evaluated [68]. All facilities contained a wet detention pond (200-250 m³ (impervious ha)⁻¹) followed by sand filters. In one facility the water from the sand filters was led through fixed media sorption filters. In another facility the pond bottom was enriched with iron salts. In the last facility aluminium was added to the incoming storm water.

The treatment system consisting of a wet retention pond, a sand filter and a fixed media sorption filter was efficient in reducing dissolved and colloidal pollutants in the storm water and the system also showed high efficiency in reducing nutrients, heavy metals and PAHs. The hydraulic capacity of the sand filter was however too low and anaerobic conditions lead to release of metals. While these and many other new storm water management technologies are focusing on removing dissolved and colloidal substances they are also efficient in reducing litter of all sizes, even if that so far has not been the focus for the technology development.

The emerging technologies of green and blue values in relation to storm water management systems have a large potential to reduce the marine litter as well as microscopic marine litter simply due to the fact that the storm water volumes produced are reduced. An increased display of the storm water systems through blue and green solutions, have further a positive effect in reducing deliberate and undeliberate littering from the public. Increased water retention in these systems will also impose more efficient reduction of microscopic litter and dissolved pollutants.

7 Waste water

7.1 Aims with waste water treatment

The original aim with waste water treatment was to reduce foul smell and it was only much later, early in the 19th century, that waste water was suspected to be coupled to the spreading of diseases. When this connection was suspected the collection and treatment of waste water became of national interests and large investments started to be put into the area of waste water collection and treatment. Both the use of sedimentation and chemicals to initiate and enhance sedimentation

as well as to use microorganisms within waste water and filtration was invented and slowly set into use to treat waste water in the late 19th century [80]. In the beginning of the 20th century the use of bacteria and microorganisms was further elaborated which resulted in the inventory of the activated sludge process in 1913, which today is the core of secondary treatment [80].

From 1965 and onwards the aim with waste water treatment turned to also encompass environmental protection [80]. It was recognised that waste water may have a large negative impact on the environment by causing decreased oxygen levels and by causing eutrophication. Discharge of organic substances may result in anoxia as oxygen is consumed during the biological degradation of the material. Elevated nutrient levels cause plankton algae blooms which reduces visibility and therefore macroalgae distribution. This environmental concern for anoxic waters and eutrophication was the main cause for the development of the European Urban Waste water Treatment Directive (UWWTD) (91/271/EEC) which is from 1991.

However, step by step it has also been recognised that waste water may contain a number of other substances of concern for the environment such as heavy metals or persistent organic pollutants which are not regulated within the Urban Waste water Directive. Emerging substances often called micro pollutants that are identified as of a major concern today includes for example: brominated flame retardants, gasoline additives; endocrine disrupting compounds, organometallics, organophosphate flame retardants, perfluorinated compounds, pharmaceuticals, industrial additives and additives within personal care products [81-84]. In these reviews and articles microlitter has not been mentioned which may be because they are not substances, or due to quite limited data on emission levels.

A simplified flow of treatment steps within European waste water treatment plants is shown in Figure 3.

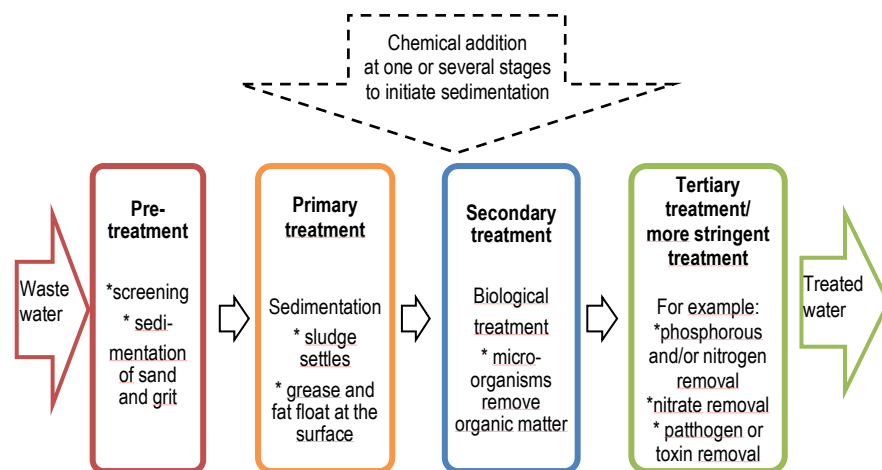


Figure 3. A general overview of treatment steps within European waste water treatment plants [85]

The different treatment stages presented in Figure 3 and used in the UWWT Directive involves the following steps:

Preliminary treatment

The preliminary or pre-treatment stage within Figure 3 is not specifically described within the UWWTD but is applied to remove constituents that may affect the operation of the plant negatively by clogging and possibly breaking pipes and pumps. During this stage large objects such as paper, plastics, pieces of rags, dead animals, tree branches etc. are removed, as well as sand and grit [86]. In this stage screens of different sizes are used which should remove some microlitter depending on the screen mesh size and amount of litter in the water. Sometimes also floatables such as oil and fat is removed which also should remove floating micro litter. According to one source this could reduce biological oxygen demand by 15-30% [86].

Primary treatment

According to the directive BOD₅ has to be reduced by at least 20% before discharge and total suspended solids have to be reduced by at least 50%. This stage usually consists of sedimentation with or without chemical additions. With plain sedimentation removal of total suspended solids is 40–90% whereas the use of chemicals increases removal to 60-90% [87]. Removal of phosphorous with plain sedimentation is 5-10% and 70-90% with the addition of chemicals. BOD₅ removal with plain sedimentation is 25–40% and with chemicals 40–70% whereas COD removal with chemical precipitation is 30–60% [87].

Secondary treatment

This stage involves biological process described above in order to reduce biochemical and chemical oxygen demand such that emission levels are reached. Thus the organisms consume and degrade the organic material within the water and up to 90% of the matter can be removed [88]. During this stage sludge is developed which could be expected to contain micro litter.

Tertiary treatment/more stringent treatment

The aim with this step depends on the receiving waters. It can be to reduce phosphorous and/or nitrogen, reduce nitrate or other substances required by other directives as described above. In order to fulfil requirements for discharge to waters sensitive to the addition of nutrients advanced biological processes are used to reduce nitrogen by the denitrification process. In order to reduce phosphorous levels membrane filters with mesh sizes of 10–20 µm may be installed. In areas where the treated water is released to shellfish waters or bathing waters disinfection processes may be applied as tertiary treatments. Due to the increased knowledge about a number of substances of concern several different processes are tested to degrade these often persistent compounds. Many of these processes use advanced oxidation processes (AOP) where reactive radicals that can degrade organic pollutants are produced [89]. Other use for example ultrafiltration, reverse osmosis and ion exchange [89].

7.2 Litter removal in waste water treatment techniques

7.2.1 Treatment mechanisms

The aim with the UWWTD is not to remove litter of any size from the waste water but several of the different treatment steps (Figure 3) and processes used within these may also remove litter from the water phase. Each of the treatment stages presented in Figure 3 is in reality designed in different ways in different European countries and also within countries. Waste water treatment techniques are often classified into three different categories according to the working mechanism:

- **Physical principles:** involves physical forces such as screening, filtration, sedimentation and flotation.

Screens are available in several sizes [87]:

- Coarse screens have size openings >6 mm and remove large solids. Some types are: reciprocating rake screens, catenary screens and continuous self-cleaning screens.
- Fine screens have size openings between 1.5–6 mm and reduce suspended solids to primary treatment levels. Some types are: rotary-drum screens, rotary-vertical disk screens, traveling water screens and vibrating screens.
- Very fine screens with openings between 0.2–1.5 mm.

Sedimentation occurs at several stages throughout the treatment plant. At the entrance of the plant it occurs when heavy particles such as grit and sand settles. Further on in the plant sedimentation occurs in sedimentation basins with or without the addition of chemicals and it also occurs in the biological treatment.

Flotation involves the injection of air bubbles into the water that adhere to particles which subsequently are transported to the surface.

- **Chemical principles:** involves the addition of chemicals to enhance the development of particles, to increase sedimentation or to introduce surfaces which attract particles. Chemicals are therefore often applied to enhance removal by physical processes. And chemicals can be added at several points within the plant to enhance sedimentation. Some established chemical technologies for nutrient removal are [90]:

Chemically enhanced primary treatment like

- i. alum addition
- ii. iron salts addition
- iii. zeolite

Some established technologies, but not commonly used, are [90]:

- iv. activated alumina media
- v. granular activated carbon

- vi. granular iron based media
- vii. powdered activated carbon

- Heat, UV–light and chemical agents such as chlorine and ozone can be added for disinfection

- **Biological principles:** involves the enhancement of biological activity. Initially this process was used to enhance the degradation of organic substances within the water in a quick and efficient way. Later on the enhancement of biological processes in both fully aerated and anoxic environments enabled increased nitrogen reduction through the introduction of the denitrification process. Some biological processes are [90] :
 - activated sludge process
 - aerated lagoon
 - trickling filters
 - rotating biological contactors
 - anaerobic digestion
 - biological nutrient removal

7.2.2 Filtration technologies

Filtration technologies reduce particles down to specific sizes. The main objective of the filtration is to reduce the amount of suspended solids (TSS) and other priority pollutants, but this should also have an effect on microlitter removal. Microfiltration is the terminology for approximate mesh-sizes of 0.1–5 μm , ultrafiltration for mesh sizes of 0.01–0.1 μm , nanofiltration for mesh sizes of 0.001–0.01 μm and reverse osmosis for mesh sizes of 0.0001–0.001 μm [91]. The smaller the pore sizes of the filters, the more particles present in the effluent waste water will be reduced.

Generally, several of the filtration techniques discussed in this section, are installed in the same WWTP. As a first step a coarse screen/sieve is already implemented in most WWTPs around the world described earlier. A pre-treatment step such as pre-sedimentation or disc filters replacing the pre-sedimentation step is also a common treatment step at WWTPs of today. After the primary and secondary treatment step, a tertiary step (polishing) may be implemented. There is an increased use of such a tertiary/final filtration step after the conventional biological and sedimentation step. The reason for this is mainly to comply with stricter regulations on phosphorus release. With limits at 0.3 mg phosphorous per litre or less it is necessary to remove most of the suspended particles since they contain phosphorus. Sand filters are very common but the market of disc filters as a polishing step is steadily growing.

Polishing by nanofiltration or reverse osmosis is still quite uncommon in the waste water treatment sector. However due to the increased need in the world to re-use treated waste water, implementation of these technologies is increasing [92]. Ultrafiltration or microfiltration is used as a pre-treatment step prior to reverse

osmosis, whereas both these technologies in series are common in waste water reclamation plants. Several of the filtration techniques using smaller pore sizes are commonly used for waste waters that are to be re-used for different purposes (eg. irrigation, groundwater recharge, industry process water).

The smaller the pore size of the filtration technology, the larger the pressure needed over the membranes will be, resulting in a higher need of pressure/pumping in connection to the technology. Furthermore the maintenance need is generally higher for technologies using smaller pore size. This is due to the filters/membranes easily being blocked resulting in a need for frequent cleaning/backwashing events of the filters/membranes. The costs, in Sweden, for installation and maintenance of the filters described below are presented in section 7.3.3.

Coarse screens/sieves as pre-treatment

In most treatment plants, the first pre-treatment step is a coarse screen or grid. This step is intended to remove particles of larger size than the opening where the normal size of the openings generally is 2–3 mm. The objective is to prevent large particles and objects from damaging downstream equipment. The screen removes objects such as toilet paper, plastic bags, condoms, tampons, ear swabs etc. that usually are grinded and then sent for further waste treatment. Other plastic items and micro litter might also be included in this material but analyses of the waste content have not been found. Some screens need to be cleaned manually by removing the attached litter by using a rake or similar tools, but most current screens are in continuous rotation or in other ways automatically rinsed, removing the attached litter into specific litter bins, whereas maintenance is only needed during periods of operational difficulties.

Sand filter

It is common in Sweden to include a filtration step, as a final polishing step, for the removal of suspended solids from waste water prior to being released into recipient. The main reason is to remove phosphorous bound in the suspended biomass. In some cases, the filtration step is also combined with a post precipitation for phosphorous removal (i.e. addition of precipitation chemical).

In a sand filter often several layers with different grain sizes and material are used, and the waste water is passing through each layer within the filter. Particles are captured on the surface of the sand grains through physical, biological and chemical processes. The filter is successively blocked by these particles resulting in a reduced flow over the filter. Once the resistance in the filter is too high, the filter needs to be cleaned. The cleaning is usually carried out by backwashing of water (in some cases also air is used) through the filter. The backwash water can then be

recirculated to the beginning of the waste water treatment line to be filtered or settled again.

Suspended solids concentration after sand filter treatment is usually < 5 mg/L, but most of this is bacterial biomass. The fraction of microlitter is not enough studied. Both particle size and surface properties of the particles determine the removal efficiency.

Disc filter

A disc filter (also called micro screening) is a common technology used as a final polishing step for the removal of suspended solids and also phosphorus. A disc filter process consists of a tank containing a number of rounded discs made of cloth media filters. Waste water is added into the tank and then passes through the rotating filter discs by gravity resulting in a relatively low energy need. The filtered water is collected inside the filter discs for discharge to effluent. The filter is successively blocked by particles attached to the cloth resulting in need for backwashing. Common filter sizes for disc filter for polishing of effluent water vary from 10–40 μm , whereas all particles with a size larger than this will not be released to recipient. During part of the filtration much smaller particles than 10 μm are removed due to filtration through the filter cake building up on the disc. Suspended solids concentration after disc filter filtration is usually < 5 mg/L. Removal is dependent on particle size. Ryaverket in Sweden (Gothenburg, 780 000 PE) installed the largest disc filter as a polishing step installation in the world in 2010.

Disc filters have also been suggested to be used as a pre-treatment step, replacing the common technology of pre-sedimentation. Sedimentation tanks are usually requiring large land areas, whereas particle separation by disc filter can be carried out on smaller areas (80% less land area needed¹), which is beneficial specifically in urban areas where land area often is a limiting factor. When using disc filter as pre-treatment, instead of the more common process of using them as a polishing step, cleaning by backwashing is required more often, due to the fact that untreated waste water contains much more particles that can block the cloth filter surface, than in the case of a waste water more close to the effluent stream.

Nano filtration

Nanofiltration is a membrane filtration technology using nanometer sized cylindrical pores. Pore sizes are ranging from 1–10 nm, and particles with a size larger than this will not be released to recipient. Nanofiltration operates at a pressure of typically 7–30 bar [93] and it has replaced reverse osmosis (RO) in many applications due to lower energy consumption (lower pressure needed) and higher flux rates [94]. Nanofiltration is currently mostly used for treatment of

¹ Personal communication Hydrotech AB, 2015

drinking [20] water, and not waste water. It is however also used as a polishing step in the case the treated waste water is to be reused for different purposes (eg. for irrigation, groundwater recharge etc.). The main objective of this treatment is then not the removal of particles as such, but for the removal of pharmaceutical residues and other priority pollutants.

Nanofiltration membranes will, as any other membrane processes, experience a reduced performance over time due to membrane fouling. The fouling can be both reversible and irreversible. Reversible fouling can be reduced by cleaning of membranes whereas irreversible fouling cannot. The cleaning process is generally carried out by backwashing with an acid for the removal of inorganic foulants and a base for the removal of organic foulants. The concentrate from nanofiltration can have a volume up to 10 % of the original influent but it contains all rejected particles and many dissolved compounds in at least 10 times larger concentration than that in the influent. Rejected materials are e.g. organic micro pollutants, heavy metals and biologically inert material [95]. Disposal of this concentrate is a complicated matter no matter if it is transported for further waste handling or recirculated to the influent of the waste water treatment plant. If recirculated to the WWTP, and if it contains toxic compounds, specifically the nitrogen removal process can be disturbed or inhibited since nitrifying bacteria are a very sensitive microorganism in the activated sludge.

Reverse osmosis (RO)

Reverse osmosis uses a semipermeable membrane for removal of particles in the waste water. The membrane is essentially non-porous and it only passes fresh water and most of the solutes are retained [93]. Reverse osmosis can remove all particles, including the smallest virus. An applied pressure, higher than for nanofiltration (typically 20–100 bar is used to overcome the osmotic pressure [93]). Reverse osmosis is currently mostly used for treatment (desalination) of drinking water, and not waste water.

As in the case of nanofiltration, reverse osmosis is also used as a polishing step for waste water to be reused for different purposes (see description for nanofiltration). Due to the smaller pore size than for the nanofiltration case, the effluent water has lower concentrations of unwanted substances and can therefore be reused in applications with tougher restrictions on water reuse quality. Microfiltration or ultrafiltration is often used as a pre-treatment step prior to the reverse osmosis treatment step. This is to reduce the fouling caused by the constituents within the waste water [96].

Also, as in the case for nanofiltration, reverse osmosis also produce a concentrate containing all the retained compounds found in the waste water. Disposal of this concentrate is complicated. Possible treatment options, if the concentrate is not recirculated to WWTP, are different advanced oxidation technologies using ozonation, hydrogen peroxide and/or UV-light [97]. If recirculated to the WWTP,

the nitrogen removal (nitrification process) needs to be carefully monitored so that the nitrifying bacteria are not disturbed or inhibited.

7.2.3 Reductions of litter by the use of different technologies

Although not many, there are some studies on microlitter in waste water and the degree of reduction due to different technologies. Recently microlitter was studied in a waste water treatment plant in Finland and micro litter concentrations were measured after three different treatment stages. It was shown that textile fibres (plastic fibres and non-synthetic fibres) were mainly reduced during the primary sedimentation step, almost not at all during the second sedimentation step and some more during the last treatment (denitrification and nitrification + filtration), see

figure 4. Regarding synthetic particles (plastic particles) primary sedimentation reduced the numbers with about 30% whereas secondary sedimentation increased the degree of reduction to about 84%. After the full treatment synthetic particles were reduced by about 98%.

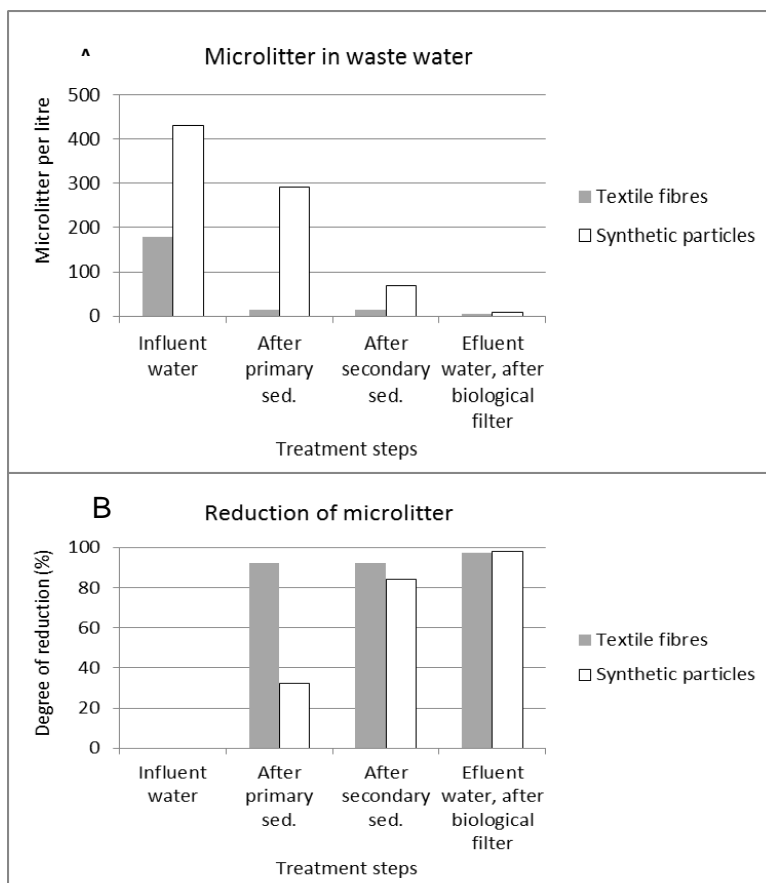


Figure 4. In A micro litter concentration per litre in influent waste water and after three different treatments in a waste water treatment plant in Finland is shown. In B the degree of reduction (%) in relation to influent water is shown after three different

treatments. Textile fibres contain both synthetic fibres (plastic fibres) and non-synthetic fibres. Data plotted after [98].

In a study in Sweden, microlitter in domestic waste water, waste water entering a WWTP, waste water after primary and secondary treatment but before disc-filter and effluent water (after disc-filter) were analysed. As seen in

Figure 5 and Figure 6 a major proportion of the litter is reduced before the disc filter but the filter reduces microlitter even more.

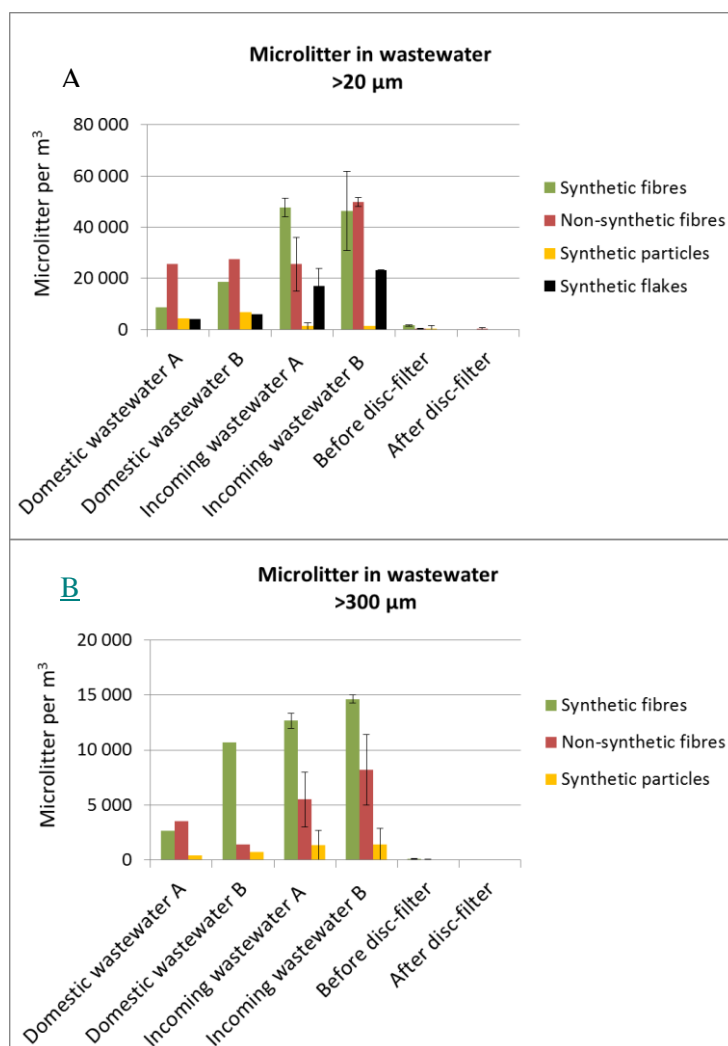


Figure 5. Microlitter in waste water in a Swedish WWTP. In Figure A waste water was filtered with 20 µm mesh. Domestic waste water was collected on the sewage system and incoming waste water at the WWTP. In Figure B waste water was filtered with 300 µm mesh. The disc-filter has a mesh of 10 µm. After [54].

In Figure 6 the reduction over the disc filter (mesh 10 μm) at the Swedish WWTP is presented.

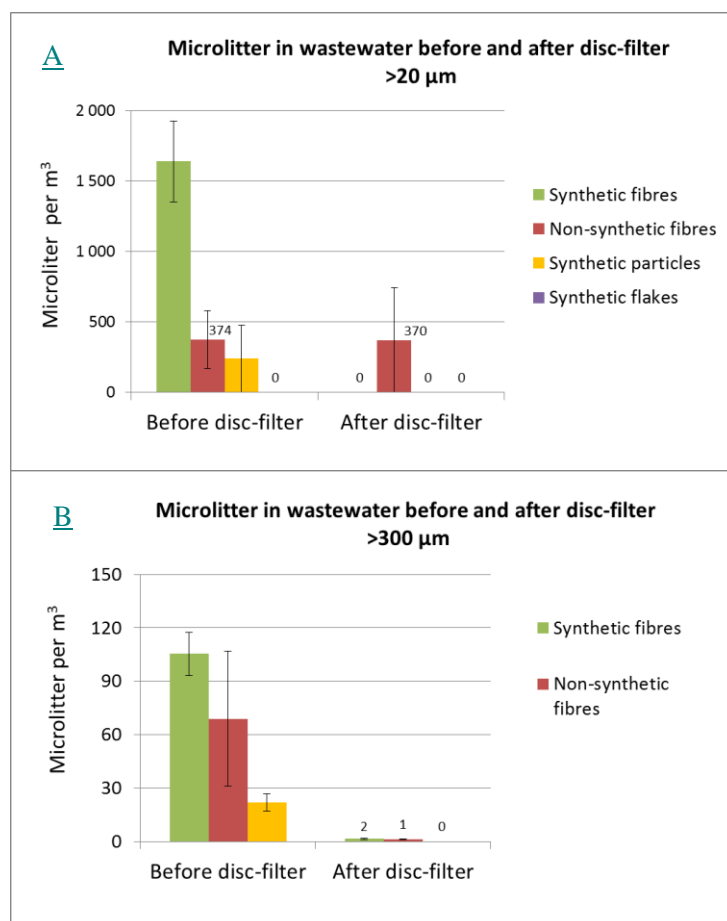


Figure 6. Microlitter in waste water in a Swedish WWTP before and after disc-filter with mesh size 10 μm . In Figure A waste water was filtered with 20 μm mesh. In Figure B waste water was filtered with 300 μm mesh. After [54].

As shown in the Swedish and Norwegian WWTPs equipped with mechanical, chemical and biological treatment of the waste water, the reduction of micro litter particles $\geq 300 \mu\text{m}$ is >99% (see Table 6). The lowest degree of treatment (mechanical and chemical, the coarse grid is not considered) has a reduction of at least 97.4%. Thus the vast majority of micro litter particles reaching the WWTPs with the influent water are retained in the sewage sludge. Larger particles are retained to a higher extent than smaller ones [25]. In spite of the large reduction efficiency, the effluent water contains a considerable number of litter particles.

**Table 6. Litter particles 300 – 5 000 µm in WWTP effluent water. WWTP 1–8 have mechanical, chemical and biological treatment, and, as marked in the table, some of them also have an additional treatment step before the water is discharged into the recipient. WWTPs 9–10 have mechanical and chemical treatment, WWTP 11–12 only have a coarse grid. The WWTPs vary considerably in size, as can be seen by the differences in person equivalent (PE).
References: ¹ [22]; ² [25]; ³[23] ; ⁴[54] .**

WWTP	Additional treatment step	Total microplastics in influent waste water (no/m3)	Total microplastics in effluent waste water (no/m3)	Reduction efficiency in WWTP (%)	Flow rate (m3/hour)
<i>Mechanical, chemical, biological treatment</i>					
WWTP 1, 800 000 PE¹	Tertiary DN–post–filtration unit	100 000	43	99.9	14 000
WWTP 2, 740 000 PE²	Disc filter, 15 µm mesh size	7 000	7	99.9	13 000
WWTP 3 62 000 PE⁴	Disc filter 10 µm mesh size	15 040	2	99.99	1 300
WWTP 4 750 000 PE²	Sand filter	9 400	4	98.9	14 400
WWTP 5 Pilot plant	Membrane Bioreactor (MBR)				Not applicable
WWTP 6, 700 000 PE³	No additional treatment	23 100	23	99.9	14 700
WWTP 8 14 000 PE²	No additional treatment	10 200	32	99.5	400
<i>Mechanical and chemical treatment</i>					
WWTP 9 185 000 PE³	No additional treatment	11 300	300	97.4	1 080
WWTP 10 85 000 PE³	No additional treatment	7 400	48	99.4	540
<i>Only coarse grid</i>					
WWTP 11 & 12	Data from two WWTPs showed large variations but indicated that the retention of microlitter particles >300 µm was very limited.				

7.2.4 Technologies reducing large particles and suspended solids

The first pre-treatment step involving grids/screens generally in place in most waste water treatment plants catch larger particles such as toilet paper but it is also not uncommon with objects such as condoms and ear swabs. Specific litter characterisations from the pre-treatment screening have unfortunately not been found, however the weight of waste that is removed from the first screen at seven of the larger waste water treatment operators in Sweden is presented in Table 7. Theoretically, pre-treatment grids/screens may also be applicable in areas with combined sewer systems prone to overflow in order to reduce discharge of large litter.

Table 7. Amount of waste collected by course screens in seven of the largest WWTPs in Sweden. Please note that the waste has not been categorised. Data has been extracted from environmental reports (from 2014) for each plant. Reported amounts are in wet weight, and the dry weight content may differ between each plant.

Plant	Size (PE)	Removed amount of waste (ton per year)	Removed amount of waste (kg/PE and year)
Henriksdal WWTP + Bromma WWTP	1 150 000	800	0.7
Ryaverket WWTP	780 000	1 000	1.3
Käppalaverket WWTP	425 000	469	1.1
Sjölunda WWTP*	370 000	433	1.2
Nykvarnsverket WWTP	180 000	286	1.6
Kungsängsverket WWTP	170 000	105	0.6
Öresundsverket WWTP*	150 000	300	2.0

*Data from 2013

The degree of reduction of microlitter by the use of specific technologies is very seldom analysed and reported as earlier stated. But, many litter particles get caught in the sewage sludge and suspended solids are generally always monitored at WWTPs. As suspended solids to some degree probably behave as microlitter, SS may be regarded as a proxy for microlitter. Therefore treatment steps and technologies that reduce suspended solids are presented below.

In an analysis of 16 UK waste water treatment plants and total suspended solids it was shown that primary treatment removed approximately 65%, secondary treatment removed approximately 25% and tertiary treatment removed about 5% of total suspended solids, see Figure 7 [99]. This is in accordance with results from Finland presented in

figure 4.

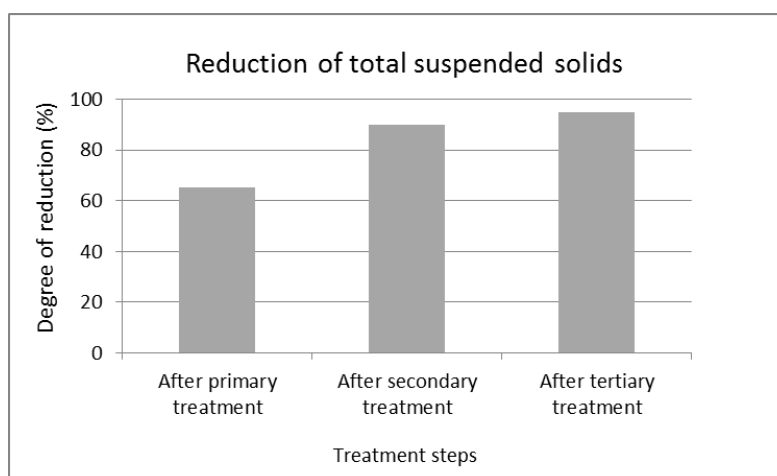


Figure 7. Reduction of total suspended solids in 16 waste water treatment plants in the UK, figure drawn after data in [99].

According to the survey² performed within this project measurements in Portugal show that grids at the inlet to the waste water treatment plant (20 mm and 3 mm) reduce total suspended solids with 5–10% (no waste categorization was performed). The primary treatment step generally reduces total suspended solids with about 40%.

In a report by COWI for the European Commission, the quality of untreated incoming waste water and waste water subjected to different treatment combinations is described which is summarized in Table 8 [100]. According to this source, suspended solids in incoming water are reduced by 30% due to the mechanical treatment (primary treatment), and if phosphorous removal is added to the mechanical treatment, suspended solids in the incoming water are reduced by 60%.

Table 8. Untreated incoming water and effluent water qualities due to different treatment combinations [100].

Treatment levels	Water quality for incoming water and effluents due to treatment level (mg/L)				
	BOD	N	NH ₄ -N	P	SS
Untreated incoming water	250	50	30	8	300
Mechanical t. (primary t.)	175	45	35	7	25
Mechanical t. with P removal	100	40	35	2	25

² See appendix 11.1 and 0.

Mechanical–biological t. (secondary t.)	25	35	30	6	25
Mechanical–biological t. with P removal	15	35	30	1	25
Mechanical–biological–nitrification t.	15	35	2	6	25
Mechanical–biological–nitrification t. with P removal	15	35	2	1	25
Mechanical–biological–nitrification–denitrification t.	15	8	2	6	25
Mechanical–biological–nitrification–denitrification t. with P removal	15	8	2	1	25

BOD= Biological oxygen demand, N= Nitrogen, NH₄-N= Ammonia nitrogen, P=Phosphorus, SS=Suspended solids

In a report on waste water technologies to treat a variety of different variables, total suspended solids and total dissolved solids (TSS, TDS) are included [101]. Based on the assumption that total suspended solids (TSS) correlate with microlitter, this is interesting and presented in Table 9. In the report TSS and TDS are presented as a group but it is probably more correct to view the information such technologies with an effects on TSS and/or TDS. Established technologies that reduce TSS and/or TDS (included as a group) are summarised in Table 9 [90]. Emergent technologies that reduce TSS and/or TDS are presented in section 7.3.2.

Table 9. Compilation of established technologies (chemical, physical and biological processes) that are used to for the reduction of total suspended solids and/or total dissolved solids (TSS/TDS) [90]. If the technology also reduces other variables this is shown by: P for phosphorus, NA for reduction of ammonia by nitrification, C for reduction of C–BOD, DN for reduction of nitrogen with denitrification and TC for reduction of targeted contaminants. In the report TSS and TDS are presented as a group but it is probably better to view the information as effects on TSS and/or TDS

Technical level and process	Technology	Reduced variables
Chemical and physical processes		
<u>Adsorption</u>	Granular activated carbon	TSS/TDS + P + DN
	Powdered activated carbon	TSS/TDS + P
<u>Nutrient removal</u>	Chemically enhanced primary treatment	TSS/TDS + P
	Denitrification filters	TSS/TDS + P + DN
	Chemical precipitation with alum addition	TSS/TDS + P
	Chemical precipitation with iron salts addition	TSS/TDS + P
	Chemical precipitation with zeolite	TSS/TDS
	Solids contact clarifier for P removal	TSS/TDS + P + NA
<u>Preliminary/primary treatment</u>	Advanced grit removal systems ³	TSS/TDS
	Gravel removal with traveling bridge	TSS/TDS
	Screening with fine, micro, rotary and step screening	TSS/TDS + (P) + TC)
<u>Solids removal</u>	Dissolved air flotation	TSS/TDS
	Automatic backwash filters	TSS/TDS + P
	Disc filter	TSS/TDS + P
	Drum filter	TSS/TDS + P
	Diamond shaped filter	TSS/TDS + P
	Pulsed bed filter	TSS/TDS + P
	Silica media	TSS/TDS + P
	Filtration through membranes– electro dialysis	TSS/TDS + TC
	Filtration through membranes– microfiltration	TSS/TDS + P + TC
	Filtration through membranes– ultrafiltration	TSS/TDS + P + TC
Biological processes		

³ Headcell™, Gritking™, Pistagrit™, Hydrogrit™.

<u><i>Nitrogen reduction</i></u>	Denitrification filter	TSS/TDS + DN
<u><i>Membrane processes</i></u>	Membrane bioreactor (MBR) <ul style="list-style-type: none"> • tubular • hollow-fibre • spiral wound • plate and frame • pleated cartridge filters 	TSS/TDS + C + P + NA

7.3 Costs per treatment level and technology

7.3.1 Costs for established treatment levels

As described earlier the UWWT Directive requires different stages of treatment levels to be accomplished (primary, secondary and tertiary) and within each of these treatment stages different technologies can be used (screens, filters, sedimentation, chemicals, biological processes etc.). As raw water conditions, waste water flow, number of PE, requirements to be fulfilled, plant location and plant age differ among plans so does also techniques and designs. If adjustments have to be conducted to increase treatment effect, possible techniques and costs therefore naturally also vary among plants.

However despite these difficulties, a comprehensive report on investment costs for member states to be compliant with the UWWT Directive was recently published wherein predicted investment costs for different treatment levels are presented ⁴ [100]. Technologies applied within the different treatment levels for which investment costs are calculated are presented in Table 10.

⁴ Costs have been developed within the model called FEASIBLE (Financing for Environmental, Affordable and Strategic Investments that Bring on Large-scale Expenditure), <http://www.cowi.com/menu/project/EconomicsManagementandPlanning/Finacialanalysesandlaw/Pages/feasiblemodel.aspx>

Table 10. Techniques and treatment levels for which costs are developed. Classification according to the registry database for national WWTPs.

Technologies	Treatment	Classification according to registry database
Mechanical	Primary treatment	1
Mechanical–Biological	Secondary treatment	2
Mechanical–Biological–Chemical	Advanced treatment with P removal	3P
Mechanical–Biological–Chemical–Nitrification	Advanced treatment with N removal	3N
Mechanical–Biological–Nitrification–Denitrification	Advanced treatment with both N and P removal	3PN

The calculation of costs is based on several assumptions for example that person equivalents are used within the cost functions and PE is = total load of biological oxygen demand divided by 60 g/day. Waste water flow is set to 200 l/PE and day and a medium quality design for the plant has been used within the calculations⁵.

⁵ Further assumptions are that $BOD_{inlet}/N_{inlet}=4.5$ and that $Peak\ flow_{rain}/Peak\ flow_{dry\ weather}$ is equal to 2.

Predicted investment costs functions for the different treatment levels and PE intervals are presented in Table 11 (Danish crowns (DKK) and 2008 price level).

Table 11. Investment cost per PE in DKK price level 2008 according to [100].

Treatment	Cost function	Cost
	(PE 2 000– 100 000) (DKK 2008 price level)	(PE >100 000) (DKK 2008 price level)
Primary	$=10^{(-0.2073*\log((PE)+3.6385))*0.23}$	92
Secondary	$=10^{(-0.2632*\log((PE)+4.0149))*0.23}$	115
3P	$=10^{(-0.2808*\log((PE)+4.1823))*0.23}$	138
3N	$=10^{(-0.2612*\log((PE)+4.2600))*0.23}$	207
3NP	$=10^{(-0.2722*\log((PE)+4.3608))*0.23}$	230

Investment costs for different treatment levels and are plotted in Figure 8.

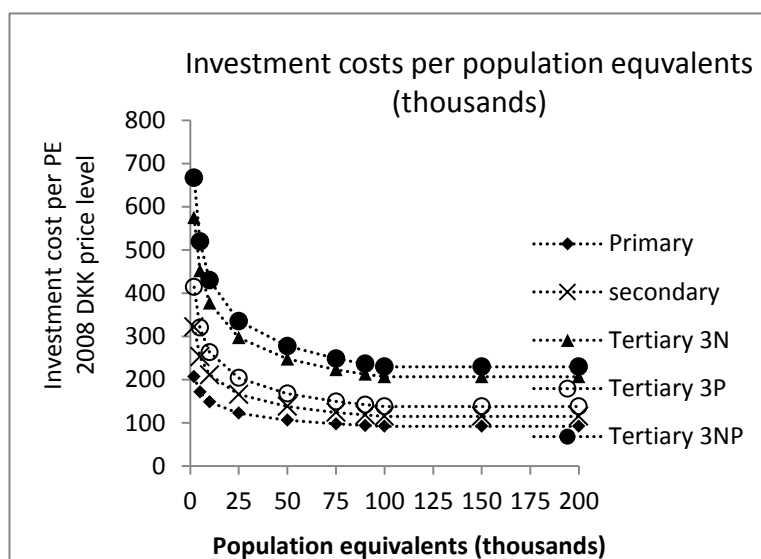


Figure 8. Investment costs for different treatment levels and population equivalents (thousands).

As costs may vary due to national price levels the report presents correction factors for material and work cost as shown in Table 12. As material costs are assumed to be under international competition the correction factor is 100% but as labour costs to a large degree are national the correction factor to be used is the national price level.

Table 12. Correction factors for investment cost for waste water treatment plants [100].

Cost category	Cost share	National price level
Materials	35%	Default is the international average price level = 100%
Civil works, design and other cost elements	65%	National price level x% compared to DK level (Eurostat's price level indicators).
<i>Correction factor</i>	35% + (x%*65)%	

An example of the calculation of the correction factor as presented in [110] is shown in Table 13.

Table 13. An example of calculation of correction factor [100].

Cost category	Cost share	Price level
Materials	35%	International average price level = 100%
Civil works, design and other cost elements	65%	National price level =75%
<i>Correction factor</i>	84%	

Uncertainty is always present and according to the experience of the authors of the report actual costs may vary from the predicted value from 50% less to 100% [100]. Deviations from the predicted cost are due to the state of the plant and need for reinvestments as well as specific conditions of the locality.

7.3.2 Costs for emerging technologies

As earlier mentioned the reduction of micro litter by different technologies is seldom described. However there are reports on investment costs for technologies reducing total suspended solids (TSS). In a recent report on emerging processes for waste water treatment, the reduction of TSS and TDS (total dissolved solids) are included [90]. In the report different development stages for technologies are used and innovative technologies are those that fit one of the following criteria:

- has been tested as a full-scale demonstration
- has been available and implemented in the United States for < five years
- has some degree of use in the United States.
- is an established technology overseas

Adaptive technologies have originally been developed for other applications but are modified for waste water. Emerging technologies are those that have been tested at a pilot/demonstration scale or have been implemented in three or fewer plants at full scale for less than one year. Technologies using chemical and/or physical processes to reduce TSS/TDS are summarised in Table 14 where the effects of these technologies on phosphorus reduction and targeted contaminants also is included [90]. In the report TSS and TDS are presented as a group but it is probably better to view the information as effects on TSS and/or TDS.

Table 14. Compilation of emerging technologies (chemical and physical processes) for the reduction of total suspended solids/total dissolved solids (TSS/TDS) [90]. If the technology also reduces other variables this is shown by: P for phosphorus and TC for targeted contaminants. In the report TSS and TDS are presented as a group but it is probably better to view the information as effects on TSS and/or TDS

Technical level and process	Technology	Reduced variables
<u>Innovative technologies</u>		
<i>Nutrient removal</i>	Blue PRO™ reactive media filtration	TSS/TDS + P
<i>Solids removal</i>	Compressed media filtration	TSS/TDS + P
	Magnetite ballasted sedimentation	TSS/TDS + P
	Multi-stage filtration	TSS/TDS + P
	Nano-filtration and reversed osmosis	TSS/TDS + P + TC
<u>Adaptive use technologies</u>		
<i>Solids removal</i>	Ballasted high rate clarification (BHRC) processes ⁶ <ul style="list-style-type: none"> • Actiflo® • Densadeg® 	TSS/TDS + P
<u>Emerging technologies</u>		
<i>Oxidation</i>	Blue CAT™	TSS/TDS + P + TC
<i>Preliminary/primary treatment</i>	Salsnes filter	Biological oxygen demand and fine primary solids

According to the USEPA-report the state of development for the innovative technologies for solids removal (Compressible media filters, Magnetite ballasted sedimentation, Multi-stage filtration and nano-filtration-reversed osmosis) is full-scale industrial applications, full-scale municipal applications and full-scale operations in North America [90]. Applicability for the first three technologies is

⁶ Actiflo® process, Densadeg® process

industry wide but for nano-filtration and reversed osmosis the technology has only been implemented in a few plants.

Capital costs and operation and maintenance costs for these emerging technologies are presented in Table 15.

Table 15. Capital and operation and maintenance cost for emerging technologies[90].

Technology	Cost
Blue PRO™ reactive media filtration Removal of phosphorus from tertiary waste water with co-precipitation and adsorption to a reactive filter media.	Capital cost for plans with a flow of 3.8 million litres/day \$178 300, plants with a flow of 11.4 litres /day \$494 000. O&M cost per year for a flow of: 3.8 million litres/day \$29 380, for a flow of 11.4 litres/day \$84 000.
Compressed media filtration Removal of phosphate, particulates and BOD with the use of a synthetic fiber media.	Equipment cost for application as a tertiary filter is less than \$0.06 per gallon capacity For the application SSO and primary effluent the cost is less than \$0.07 per gallon capacity.
Magnetite ballasted sedimentation Enhanced removal of suspended solids. For tertiary treatment or high-rate treatment of overflows.	No information.
Multi-stage filtration Removal of solids containing nitrogen and phosphorus	Costs vary with technology and performance requirements.
Nano-filtration and reversed osmosis Tertiary membrane filtration for advanced treatment of secondary effluent. Nano filtration have pore size 0.001–0.01 µm and reversed osmosis 0.0001–0.001 µm.	Costs described as not available.
Actiflo® Treatment of primary and tertiary effluents with chemical and physical process where suspended solids can adhere to ballast particles (sand).	Costs are described as not disclosed by the vendor.
Densadeg® Treatment of primary and tertiary effluents with sludge ballasted clarification and lamellar filtration to remove solids.	Costs are described as dependent on local requirements and applications.
Blue CAT™ Removal of micro-pollutants such as endocrine disruptors and adsorption of macro contaminants such as phosphorus. Uses adsorption filter with advanced oxidation process.	No cost information because lack of full-scale installations.
Salsnes filter Removal of fine primary solids using a rotating belt screen. Performance is equal or better than traditional primary clarifiers.	Capital cost is 30–50% less than for primary clarifiers.

Biological processes are also used within waste water treatment. In the report by EPA a large number of technologies for biological processes are presented and discussed, both established, innovative and adaptive use are presented. However, only a few of these technologies reduce TSS/TDS which are presented in Table 16.

Table 16. Compilation of emerging technologies (biological processes) for the reduction of total suspended solids/total dissolved solids (TSS/TDS)[90]. If the technology also reduces other variables this is shown by: P for phosphorus, NA for reduction of ammonia by nitrification, C for reduction of C–BOD, DN for reduction of nitrogen with denitrification and TC for reduction of targeted contaminants.

Technical level and process	Technology	Reduced variables
<u>Innovative technologies</u>		
<i>Solids settling</i>	Magnetite ballasted activated sludge	TSS/TDS + C + P + NA+ DN
<u>Emerging technologies</u>		
<i>Membrane processes</i>	Membrane biofilm reactor (MBfR). <i>The process is gas driven and does not use a real membrane thus filtration is not performed and removal of micro litter probably not performed.</i>	TSS/TDS + C + P + NA+ TC
	Vacuum rotation membrane system (VRM®).	TSS/TDS + C + P

Costs for these emerging technologies using biological processes are presented in Table 17.

Table 17. Capital, operation and maintenance cost for emerging technologies using biological processes [90].

Technology	Cost
Magnetite ballasted activated sludge Increases settling rate to remove solids. Magnetite increases density of flocs.	Prices are driven by many factors but early tests indicate that capital costs for BioMag™ are comparable to competing solutions.
Vacuum rotation membrane system (VRM®) Ultrafiltration with membranes with a pore size of approximately 38 nm.	There are no installations in the United States and therefore no costs.

7.3.3 Costs for installation and maintenance of some technologies in Sweden

Through personal communication with retailers in Sweden, investment costs and maintenance costs have been gathered⁷ and presented in Table 18 for two plant sizes: 10 000 PE and 100 000 PE (1 PE = 160 L water per day). Once again it

⁷ Personal communication with Hydrotech, Nordic Water, Mercatus and Conpura.

should be noted that installation of several of these technologies is common at WWTPs of today and they are not primarily installed for the removal of microlitter but for the removal of suspended solids, nutrients, pharmaceutical residues and other priority pollutants (such as plasticisers, phenolic substances, flame retardants etc.). The investment costs listed below should therefore not only be connected to the removal of microlitter, but to the removal of several other pollutants as well.

Table 18. Investment costs for selected technologies for microlitter removal and two different plant sizes. Costs are received from various suppliers within Sweden. SEK = Swedish krona. 1.00 SEK = 0.107 EUR (January 2016). (M = million).

Technology	Plant load		Expected life time (years)
	10 000 PE	100 000 PE	
Pre-treatment step			
<i>Coarse screen/sieve</i>	200 000 SEK	500 000 SEK	20
<i>Disc filter (replacing pre-sedimentation)</i>	250 000 SEK	1 MSEK	10
Polishing step			
<i>Sand filter</i>	2 000 SEK	5 MSEK	20
<i>Disc filter</i>	300 000 SEK	1 MSEK	15
<i>Nano filtration</i>	5.5 MSEK	44 MSK	10
<i>Reverse osmosis</i>	7 MSEK	55 MSEK	10

In the case of disc filters (both as a pre-treatment step and as a polishing step), the cost depends on whether there are existing empty concrete basins available at the plant or not. If not, tank filters (tanks made of stainless steel that can be placed directly on the floor) is preferable. If empty basins are available, stand filters can be installed directly in the basins, which can induce a small reduction of the cost. The costs in the table above are based on installation of tank filters⁸

Normally, the total energy consumption at Swedish WWTPs varies between 40-80 kWh/PE and year [102]. The majority of this energy (up to 60 %) is used for aeration of the activated sludge for nitrogen removal.

Based on data from the company Conpura, the energy needed for the coarse grid is 0.02 kWh/PE and year for a 10 000 PE plant (160 l/PE and day) and 0.003 kWh/PE and year for a 100 000 PE plant (160 l/PE and day).

Based on data from Hydrotech the energy needed for a disc filter used as a pre-treatment step and as a polishing step are more or less the same but it varies with plant size: 0.01 kWh/m³ for a plant dimensioned for 10 000 PE and about 0.004 kWh/m³ for a plant dimensioned for 100 000 PE. This corresponds to about

⁸ Personal communication with Hydrotech

0.6 kWh/PE and year for a plant dimensioned for 10 000 PE and 0.2 kWh/PE and year for a plant dimensioned for 100 000 PE.

All technologies listed above also come with different needs of maintenance, energy and waste management. The costs of these are difficult to specify since they are very plant dependent, but they can at least be ranked among each other based on the different needs for each technology, (see Table 19). Compared to the total energy use in the plant, and specifically the use for aeration, the energy need for all the technologies is comparably low.

Table 19. Maintenance need, energy need and waste management need (ranked from the highest need =5 to the lowest need =1).

Technology	Maintenance need	Energy need	Waste management need
Pre-treatment step			
<i>Coarse screen/sieve</i>	1	1	2
<i>Disc filter (replacing pre-sedimentation)</i>	3	2	1
Polishing step			
<i>Sand filter</i>	1	2	2
<i>Disc filter</i>	2	2	1
<i>Nanofiltration</i>	4	4	4
<i>Reverse osmosis</i>	5	5	5

8 Survey in the OSPAR region on the current knowledge on the reduction of litter in waste water and storm water

A survey on the subject was sent to OSPAR members within the Regional Action Plan (RAP) for Marine Litter during the autumn of 2015. The survey was initiated in order to make it possible for all members to share their knowledge on the subject and present grey literature that usually is difficult to find. The question and answers are given in Appendix 11.1 and 11.2. Four OSPAR members answered the survey including Portugal, Spain, Denmark and Sweden.

The respondents from Portugal were not aware of any studies or grey literature on quantifications of litter or litter reduction data for different techniques. However

Portugal shared unpublished data on the reduction of TSS at the inlet to the waste water treatment plants which is added to section 7.2.2 above. To reduce the amount of litter reaching the sea, storm water drainage systems are for example equipped with grids and infiltration is also being used. Águas de Portugal has in the past built some plants for storm water treatment and in these plants litter reduction systems were in use. Systems to reduce litter are also used in waste water treatment plants.

The Danish respondents informed that two reports on microplastics in Denmark were published during 2015^{9,10}. According to one of the reports there is no information on microplastics in storm water in Denmark [20].

In Spain they have developed dimensioning standards for storm tanks, according to the Manual of recommendations for the design of storm tanks prepared by the Spanish Ministry of Agriculture, Food and Environment in 2014. Storm tanks allow controlling input flow and further processing in WWTP. This measure implies the reduction and removal of floating litter and proper treatment to reduce concentrations of pollutants.

IVL Swedish Environmental Research Institute was responsible for contacting relevant actors in Sweden. The received feedback from these actors has been a key element in this report.

9 Industrial waste water

Industrial waste water is not included within this report as a separate subject such as waste water and storm water. However, industrial waste water may be released after treatment at the industry directly to the ocean without passing a municipal/urban waste water treatment plant. The number of industries with direct discharge to the ocean of treated waste water is however not known. The occurrence of these discharge points is probably much lower than waste water treatment plant discharge points and for certain less than the number of storm water discharge points. Thus the total discharge volume is probably also less. However in the continuous search for sources of litter it is important to be aware of these sources. What kind of industries that have or may have litter in the waste water needs to be studied, as well as treatment technologies used and reduction levels achieved.

⁹ "Mikroplast i spildevand fra renselanlæg"

¹⁰ "Microplastics - Occurrence, effects and sources of releases to the environment in Denmark"

10 Conclusions

The microplastics found in the North Sea come mainly or completely from the region itself and not from the surrounding sea areas. The marine litter is considered to be dominated by land-based sources. Discharge from storm water drains and untreated municipal sewerage is depicted as the major land-based pathways.

The information on the transport from source to storm water and to the sea is sparse and relies on screening studies based on few samples. Research is needed to describe the processes and the magnitude of the load on the sea specifically regarding microscopic litter.

The traditional storm water treatment technologies such as wet-basin ponds are evaluated to give relatively high reduction efficiency with regard to total suspended solids. However they are poor in reduction for dissolved and colloidal pollutants.

The emerging technologies of green and blue values in relation to storm water management systems have a large potential to reduce the marine litter as well as microscopic marine litter and dissolved pollutants. Storm water management reduces storm water volumes. Moreover, increased visibility of storm water systems reduce deliberate and undeliberate littering by the population and increased retention time of the storm water enhance the reduction efficiency.

Waste water emerging substances often called micropollutants are identified as of a major concern today, however microlitter have so far not been included in the recent studies of emerging pollutants.

Regarding municipal waste water treatment systems applied today in Norway and Sweden, the reduction of litter has not been extensively monitored, but can be concluded to be efficient (>97%) based on the reduction of suspended solids and assuming suspended solids may be regarded as a proxy for microlitter.

Inlet grid removes between 5-10% of the suspended solids. Primary treatment removes approximately 30-65%, secondary treatment removed approximately 25% and tertiary treatment removed about 5% of total suspended solids

Theoretically, pre-treatment grids/screens may also be applicable in areas with combined sewer systems prone to overflow in order to reduce discharge of large litter.

For synthetic particles (plastic particles), secondary sedimentation increased the degree of reduction to about 84%. After the full treatment synthetic particles were reduced by about 98% even though removal of litter is not in focus in the treatment technologies.

To comply with stricter regulations on phosphorus, disc filter techniques are more widely applied today which enhance the reduction of suspended solids and thus microlitter. Waste water treatment plants in Norway and Sweden including disc

filters additionally to primary, secondary and biologic treatment show >99% reduction efficiency of total suspended solids.

The investment costs of disc filter, 1 MSEK, are double the cost of a coarse grid/screen, but only one fifth of the cost for a sand filter. The costs for advanced technology of nanofiltration and reversed osmosis are 44MSEK and 55 MSEK (plant load 100,000 PE).

The developments in OSPAR member states of reducing release of untreated waste water and to include conventional primary and secondary treatment of the municipal waste water treatment would at the same time have a substantial effect in reduction of the marine litter.

11 Appendixes

11.1 Survey on the current knowledge/grey literature on the reduction of litter in waste water and storm water

An internet survey with 15 questions was sent to OSPAR-members within the regional action plan on marine litter. The survey is presented below.

Survey on the current knowledge/grey literature on the reduction of litter in waste water and storm water

The occurrence of litter in the sea has been recognized as a serious threat to the marine ecosystems. Marine litter may derive from different sources, and two entrance routes are effluent water from waste water treatment plants and run off from land via storm water.

This survey has been initiated in order to gather what is known about the reduction of litter (large items and microscopic) using various existing techniques used to treat waste water and storm water in countries within the OSPAR region. The survey is specifically intended to gather informal data/grey literature that is not presented in peer reviewed literature. As the UWWT Directive is not designed to reduce the amount of litter peer reviewed knowledge on litter reduction using physical, chemical and biological treatment is scarce. However, litter is reduced in the UWWT plants and we want to know if such studies are done and if so how much litter is reduced using these different techniques/treatment levels. We assume that all UWWT plans are compliant with the UWWT Directive or are in the process of being made compliant.

In the same sense storm water treatments techniques are mainly designed to prevent flooding but may also be designed to reduce pollutants. But many of these techniques may also reduce the amount of litter. Therefore we are interested in informal knowledge/grey literature on storm water treatment techniques and their degree of litter reduction including micro litter.

The results from this survey will be presented in a progress report on available techniques and their efficiency to reduce litter in waste water and in storm water at EIHA 2016. This progress report is part of Action 42 within the OSPAR Regional Action Plan (RAP) for Prevention and Management of Marine Litter in the North-East Atlantic. Action 42 is part of RAP Theme B: Actions to combat land-based sources of marine litter.

These questions can be answered by the OSPAR RAP ML representative or whoever he or she finds best suited to act as a respondent. If you select a respondent please send the hyperlink of the survey to him or her.

We appreciate your contribution very much and thank you in advance for taking

the time to answer.

If you have any questions please contact: Katja Norén at IVL Swedish Environmental Research Institute

katja.noren@ivl.se

1) On behalf of which organisation and country are you answering?

2) Is it your perception that storm water generally is considered as a source of marine litter/ marine plastics including micro litter /micro plastics by storm water managers in your country?

Please describe briefly what you know.

3) Do you know of any studies/grey literature on marine litter including micro litter in storm water in your country?

If your answer is yes please describe briefly what you know and where you got the information from.

4) Do you know if consideration is given to the reduction in the amount of litter including micro litter when building new or upgrading existing systems for storm water handling in your country?

Please describe briefly what you know.

5) Do you know of any reports/measurements on marine litter including micro litter arising from discharges from waste water treatment plants (WWTPs) or combined storm water overflows in your country?

If your answer was yes please describe briefly what you know and where you got the information from.

6) Do you know if consideration is given to the reduction in the amount of litter including micro litter in effluent water when building or upgrading existing WWTPs in your country? This is of course beyond the requirements of the UWWT Directive.

Please describe briefly what you know.

The following questions are more detailed

7) Do you know of any reports/measurements describing the amount (volume/weight/number of particles) of litter that is captured from combined sewer overflows by the use of grids?

If so please describe the source of knowledge (title and author) and the dimension of the mechanical screen or grid (minimum aperture size – mm).

As treatment levels according to the UWWT Directive is coupled to cost we would like to know the degree of litter reduction at each level. This is the cause for the four following quite similar questions

8) Do you know of any reports/measurements describing the amount (volume/weight/number of particles) of litter that is captured from waste water by the use of merely mechanical screens or grids?

If so please describe the source of knowledge (title and author) and the dimension of the mechanical screen or grid (minimum aperture size – mm).

9) Do you know of any reports/measurements describing the amount (volume/weight/number of particles) of litter that is reduced specifically using primary treatment according to the UWWT Directive (mechanical screening and sedimentation).

If so please describe the source of knowledge (title and author).

10) Do you know of any reports/measurements describing the amount (volume/weight/number of particles) of litter that is reduced specifically using secondary treatment according to the UWWT Directive (settlement, biological treatment etc.)?

If so please describe the source of knowledge (title and author).

11) Do you know of any reports/measurements describing the amount (volume/weight/number of particles) of litter that is reduced specifically using tertiary treatment according to the UWWT Directive?

If so please describe the source of knowledge (title and author).

The following questions are related to storm water

12) Is storm water (that is not combined with waste water) treated by one or several of the techniques listed below in order to reduce litter in your country?

Please check mark these techniques.

- Catch basins with screen/grid at inlet
- Bioretention systems/bio swales
- Sedimentation basin/dam
- Infiltration
- Gross solid/pollutant trap
- Catch pit/catch basin inserts
- End-of-pipe screening devices
- Filters
- Booms for floating litter
- Permeable pavement
- Constructed ponds/wetlands
- None of the above
- Do not know

13) Please check mark the techniques below for which you have information on litter reduction levels.

- Catch basins with screen/grid at inlet
- Bioretention systems/bio swales
- Sedimentation basin/dam
- Infiltration
- Gross solid/pollutant trap
- Catch pit/catch basin inserts
- End-of-pipe screening devices
- Filters
- Booms for floating litter
- Permeable pavement
- Constructed ponds/wetlands
- None of the above

Do not know

14) Please describe the litter reduction levels for these techniques and from where you got the information.

15) Are there other treatment systems for storm water that you know can reduce litter?

If so please describe the source of knowledge (title and author).

Thank you very much for taking the time to participate!

Please, feel free to add any additional comments that you think are important.

11.2 Answers to the 15 questions within the survey

1. The survey was answered by: Directorate-General for Marine Resources, Security and Maritime Services (DGRM) and Environment (APA) / Portugal
2. Yes, we have the perception that storm water can be a source of marine litter/ marine plastics, but we haven't studies that allows the quantification of such pollution. With a few exceptions the storm water management is made by municipalities.
3. Not aware of any. We need more time to check this information. If we find any, we'll let you know
4. The storm water drainage systems takes into account minimizing the amount of waste that reaches the sea through the placement, for example, of grids. Furthermore, the Water management authority (Águas de Portugal, AdP) have built in the past some few plants dedicated to storm water treatment. In these cases, litter reduction systems are specifically foreseen.
5. AdP (Águas de Portugal) have made some studies concerning the impact of our facilities in marine environment. These studies/measurements have been made in order to justify the impact of these plants on the final discharge environment
6. Yes, this is foreseen. Systems of restraint are used
7. AdP group (Águas de Portugal) has a registration system for sand, screened material and other products removed in our plants. For these reason, we have data that allows estimate the amount (volume) removed in preliminary treatment of our plants as well the production per capita. AdP uses a 2 grid steps (the first one with 20 mm and the second one with 3 mm.
8. With a 3 mm screening device we usually remove around 5–10% of SST (total suspended solids). This is unpublished data
9. Around 40% on SST (total suspended solids) content. This is unpublished data.
10. No. We only quantify the amount of sludge that results from biological treatment reported for UWWT Directive.
11. No. We only quantify the amount of sludge that results from biological treatment reported for UWWT Directive.
12. Catch basins with screen/grid at inlet, Infiltration
13. Catch basins with screen/grid at inlet, Infiltration
14. –
15. Primary sedimentation (Suez technology, Veolia Technology)
- 16.

-
1. The survey was answered by: Danish Ministry of the Environment and Food, Nature Agency, Denmark

The answer was as follows: We have knowledge on this issue due to a study on microplastics "Microplastics – Occurrence, effects and sources of releases to the environment in Denmark" from the Danish Environmental Agency. This study was published in November 2015. The study contains a review of existing knowledge on issues related to contamination by microplastic with a focus on the use and release of microplastics in Denmark and the occurrence of microplastics in the surrounding waters. Link to the study:

<http://www2.mst.dk/Udgiv/publications/2015/10/978-87-93352-80-3.pdf>.

Furthermore, in June 2015 the Danish organisation on water and waste water DANVA published a study on microplastics in discharges from waste water treatment plants "Mikroplast i spildevand fra renseanlæg". It is a study on the sources of the load with microplastics at the waste water treatment plants, the fate of the particles in the plants as well as in the freshwater and marine aquatic environment. Unfortunately, the study is not translated into English. Link to the study:

<http://www.danva.dk/DANVA/Publikationer/Detaljer/Mikroplast-i-spildevand-fra-renseanl%C3%A6g.aspx?q=Mikroplast+i+spildevand>

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