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Summary report Plastic litter in Rhine, Meuse and Scheldt, contribution to plastic litter in the North Sea

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Samenvatting
This desk study was based on a quick-scan and it describes and analyses the origin and transport of plastic litter in the river basins of the three main Dutch rivers Rhine, Meuse and Scheldt. Furthermore, it provides preliminary estimates of the contribution of these rivers to the total amount of plastic litter in the North Sea. This research was commissioned by the Dutch Ministry of Infrastructure and the Environment to inform the international River Commissions on the scope of the plastic litter problem in their rivers and the contribution of these rivers to litter in the North Sea. This report is a summary of a more extensive report with supporting data and references. Finally, this study gives recommendations for further research in order to obtain more information, where this is not yet available.

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Contents

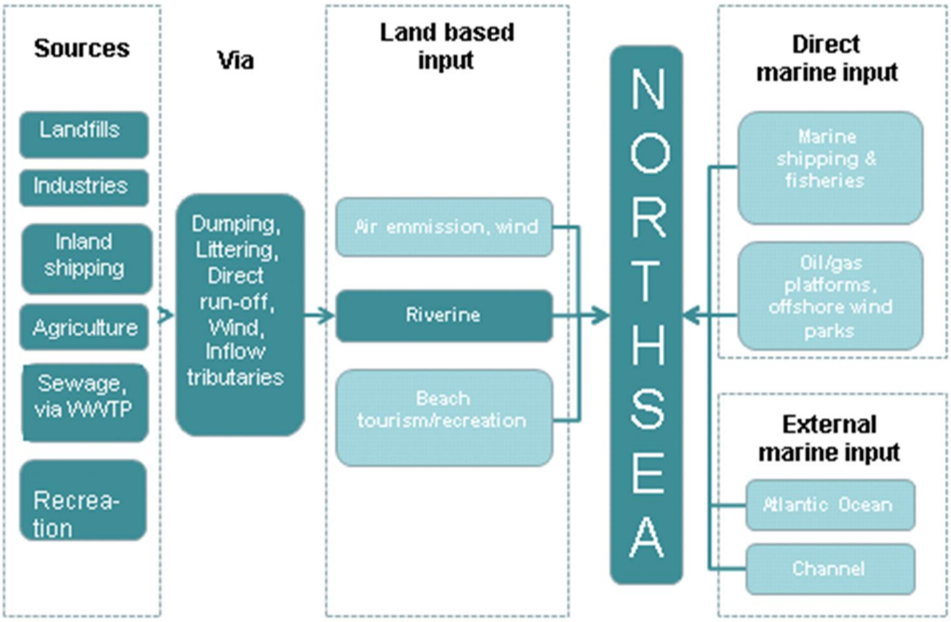
1 Introduction

The Marine Strategy Framework Directive (MSFD) establishes a framework within which Member States shall take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 at the latest. The MSFD.installed to ensure Good Environmental Status (GES) by 2020 includes the qualitative descriptor ‘Marine Litter’ (MSFD, Annex I, descriptor 10).
For freshwater, one of the main policy instruments is the Water Framework Directive (WFD), which does not include litter in determining ecological status for freshwater bodies. National authorities in the Netherlands are currently implementing the MSFD and need to provide the European Commission with data on the amounts of litter in the Dutch part of the North Sea. A main part of the marine litter is thought to be plastics that originate from land based sources and are transported via rivers. To reduce the amount of litter at sea, appropriate measures in rivers could be implemented.
This desk study was based on a quick-scan and it describes and analyses the origin and transport of plastic litter in the river basins of the three main Dutch rivers Rhine, Meuse and Scheldt. Furthermore, it provides preliminary estimates of the contribution of these rivers to the total amount of plastic litter in the North Sea. This research was commissioned by the Dutch Ministry of Infrastructure and the Environment to inform the international River Commissions on the scope of the plastic litter problem in their rivers and the contribution of these rivers to litter in the North Sea. This report is a summary of a more extensive report with supporting data and references. Finally, this study gives recommendations for further research in order to obtain more information, where this is not yet available.

1.1 Definitions, sources and pathways

In this study the focus lies on plastic litter due to its longevity and the fact that plastic litter is currently seen as one of the emerging environmental problems. Plastics, such as polyethylene and polystyrene, are synthetic molecules that are formed by joining monomers or by creating a free radical monomer which produces a long chain polymer. The unique properties and societal benefits of plastics have led to an increased global plastic consumption resulting in a growing accumulation of end-of-life plastics. Plastics discarded off improperly end up in the environment, both land and water. Rivers are transport pathways that carry litter into the seas and oceans. In general, rivers/terrestrial sources, shipping and fisheries are thought to be the major sources of plastic litter in the North Sea (see Figure 1).

Plastic litter can be classified, according to international guidelines, as macroplastics (particles larger than 5 mm) or microplastics (particles smaller than 5 mm). Probably a major part of microplastics derive from the degradation of larger plastic items (also called secondary microplastics) under the influence of UV-radiation and mechanical weathering. Primary microplastics, originating from cosmetics, household and industrial products are another source. The nanoplastics (particles smaller than 100 um) are a special class of plastic litter. Nanoplastics are not subject of this study because of lack of field data.



Items on a dark blue background are subject of this study

Figure 1 : Schematisation of sources and pathways of litter to the North Sea.

The sources mentioned in figure 1 are not evenly distributed over a catchment. To characterize the distribution of these sources we have schematized a river system in five main elements:

- A main river channel with floodplains including side channels,
- Inflow from tributaries including surface runoff,
- Rural areas,
- Nature reserves and
- Urban areas, including industrialised areas, bordering to a river.

Plastic litter from human activities in a major river derives from floodplains, urban and rural areas or tributaries. The highest concentrations of plastic litter are often found in urban areas and the lowest concentrations in nature reserves. Plastic litter in floodplains is part of the transportation route via a river. If a catchment covers different countries, transboundary litter is transported from neighbouring countries.

1.2 Effects of plastic litter in the aquatic environment

At least over 100 species of biota in the marine environment are negatively affected by plastic litter. Entanglement and ingestion of macroplastics are the main effects, causing wounds and immobility as well as blockages of the intestinal tract, gastric enzyme secretion and hormonal imbalances. These processes can lead to reduced food uptake, reproductive failures, internal injuries and eventually death. Smaller microplastics can be taken up by organisms and may cause particle toxicity. An additional chemical risk is posed by the chemical contaminants absorbed by plastic and plastic particles acting as a vector for the transport of chemical substances. It is expected that leaching of chemicals after ingestion may occur at a higher rate for microplastics than with larger plastic particles, due to their large surface-area-to-volume ratio. Furthermore, the chemical additives associated with plastics (‘plasticisers’) are released into the environment as items degrade. Plastics may also serve as a medium for invasive species and pathogens. Bioaccumulation of plastic particles and plasticisers is a potential risk for organisms higher up the food chain. The longevity of (micro)plastics combined with the potential accumulation of these particles in the foodchain poses a potential human health hazard. So far, little research has been conducted on these phenomena hampering an adequate assessment of the various risks for marine biota, marine ecosystems and human consumers of fish and shellfish products. However, recently, there is increasing evidence of bioaccumulation, toxicity and adverse physical, biological and chemical effects of microplastics and associated contaminants on a range of marine organisms and populations.

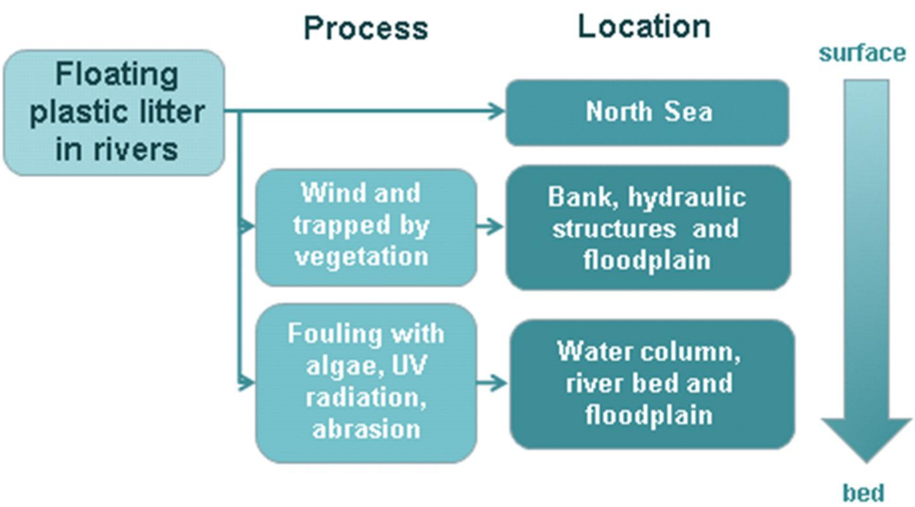
Similar effects are expected to occur in freshwater biota; however, research on freshwater biota and environments is still very limited. Organisms in areas with stagnant waters or waters with low turbulence are probably exposed to the highest concentrations of plastics, since plastic particles are most likely to accumulate there.

2 Transport processes of plastic litter

2.1 Processes in rivers

The transport of plastic litter in rivers occurs through different transport modes: a minor fraction floats on the water surface, a major fraction is transported in suspension in the water column and a small fraction is transported as part of the bed load transport near the bottom of a river. The most visible fraction is a coarse fraction (≥25 mm) of floating plastic litter during floods. The transport of plastic litter often with a foil like shape is the so-called suspended load, which stays in the water column for extensive periods of time because of the upward forces part of the natural turbulent fluctuations in flowing water. A small part of the plastic litter, those with a higher density than water, sinks to the river bed and eventually becomes part of the bed load transport process. The propagating velocity of the bed load is much smaller than the velocity of the flow.

The plastic fraction of the total volume of floating debris during normal flow appears to be small, since debris at the water surface mainly consists of organic material such as branches, roots and leafs. Since floating plastic litter is most visible, it receives most attention from the general public and researchers alike, however it is not representative of the total amount of plastics present in the considered river systems, where plastic litter occurs mainly in the water column and river bed. The highest concentration of plastic litter is observed during floods as floodplains are inundated. The dispersed plastic litter may be transported further downstream with a next flood. The pathway of floating plastic litter is determined by flow lines at the water surface and the force exerted by wind on floating litter. A pathway ends temporarily at a bank, in vegetation topping above the water level or at hydraulic structures (Figure 2). Floating plastic litter ends up in the North Sea either directly or when it size decreases by UV radiation and abrasion to micro plastic particles transported in suspension, or when the weight increases by fouling with algae that attach to plastic particles where they become part of the very slow bed load transport process.



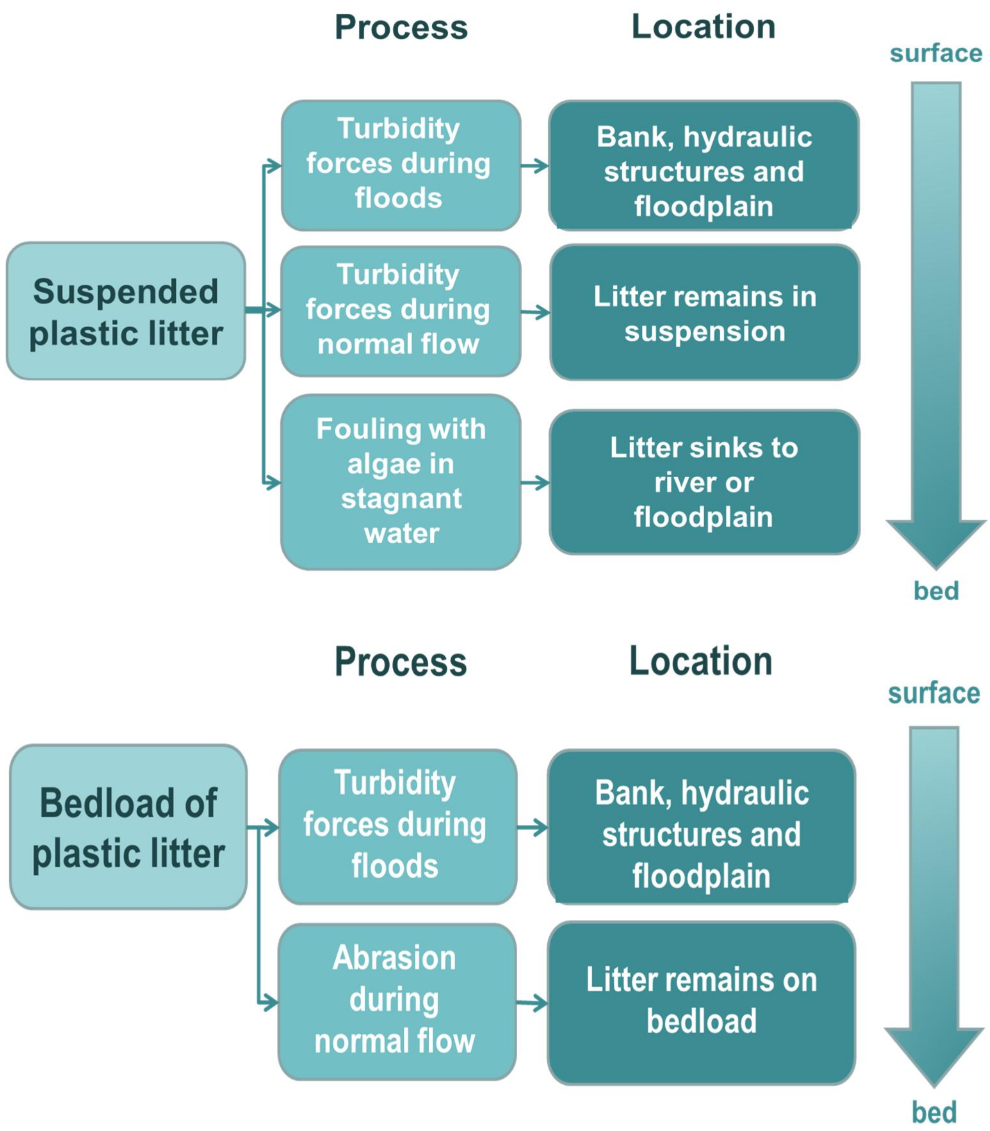


Figure 2 Scheme for the transport of floating, suspended and bed load processes of plastic litter in rivers.

2.2 Methodology and data availability

In general, data on litter and debris in West European river systems are collected and documented in a scattered manner. In this report, we used data from voluntary clean-ups and some field measurements conducted in the river Meuse as a basis for calculations and estimates on the contribution of Dutch rivers to litter in the North Sea.

Contractors, often assigned by water management organisations and municipalities, remove large volumes of floating debris from dykes and upstream of hydraulic structures after a flood. These data are limited and difficult to access. Data on voluntary clean-ups are more suitable for this quick-scan, since they give a rough indication of the total volume of removed litter and are available through media such as newspapers. Unfortunately, these data are not validated and the percentage of plastic litter, its composition and sources are often not documented. Also, it appears that the volumes of litter collected through voluntary clean-ups are relatively small compared with the clean-ups carried out by water management organisations, which in

turn are small compared to the total amounts of litter in the aquatic system. This can cause a significant underestimation of total amounts of plastic litter from rivers. No complete data sets are available on the presence, contribution and transport of litter in harbour-regions in the Netherlands and Belgium.
Since data on micro and nano-scale plastic particles in the catchment areas of the studied rivers are not available yet or very scarce, only very rough estimations could be made of the amount of this plastic fraction, particularly on the discharge of microplastics by sewage treatment plants. Estimates were based on a study conducted by Leslie et al. on microplastics in the effluent of wastewater treatment plants.
Fortunately, some preliminary data were available from field measurements as part of the MosaPura project. In this project, data on the transport of plastic litter in the water column and on the riverbed were collected by sailing a small boat with a net in a cage-like construction across the water surface at different water levels and locations.

With the available data, simple mass balance models were applied to river stretches to assess the transport of plastic litter. The contribution by a river to the pollution of plastic litter in the North Sea was estimated by extrapolating the results of these models. In the analysis it was assumed that a contribution by a river is proportional to the size of the catchment area or the average river discharge.

Figure 3. Bank of the river Meuse near Borgharen, 10 January 2011 (courtesy Mrs Wolthuis)

3 Quantification of transported plastic litter

The available data were analysed and applied as input for a simple mass balance model of the coarse fraction of plastic litter on three stretches Maastricht – Sambeek (Meuse), Sambeek – Biesbosch (Meuse), and Brussels – downstream Antwerp (Western Scheldt) covering a period with a high river discharge. Therefore several assumptions and extrapolations were made to assess the contribution to the plastic litter in the North Sea:

- It was assumed that on average 1,5 litter item per km^2 of catchment area was transported by a river based on data from waterboards,
- It was assumed that a bag of litter collected in a clean-up had a volume of 0.015 m^3 and a container had a volume of about 1 m^3 estimated from photographs,
- The weight of 1 ton plastic debris of mainly small items was assumed to fill a volume of 1.5 m^3 with a porosity of about 25 %,
- River debris might contain 10 to 20 % of volume plastic items estimated from photographs.

All these assumptions need refinement as more data become available in future.

3.1 Contribution to litter in the North Sea

The estimated volumes of plastic litter discharged via the Rhine, Meuse, Scheldt and Ems rivers in the North Sea might range from 785 to 7,850 m^3 macroplastics/year based on the extrapolation of data from clean-ups, removal by water management organisations and field measurements, see Table 1.

This discharge might be compared to the estimated volume of litter in the North Sea of about 60,000 m^3 of which about 30,000 m^3 or 20,000 ton from navigation only. If the residence time of floating plastic litter item is estimated at 2 years on average in the North Sea, than the yearly inflow from all rivers is estimated at 15,000 m^3 macroplastics/year. Assuming that the contribution by the Rhine, Meuse, Scheldt and Ems rivers is proportional to their catchment area (30% of the total area of the catchment discharging in the North Sea) we estimate that these rivers contribute 0.30 * 15,000 = 4,500 m^3 macroplastics/year. All these catchment areas are presented in a map of rivers discharging in the North Sea, see Figure 4.

This number fits well with the mentioned range for the discharge of macroplastic litter by these three rivers, 785 to 7,850 m^3 macroplastics/year, see Table 1. The litter discharged by the rivers Rhine, Meuse, Scheldt and Ems moves along the Dutch coast in Northern direction, see the arrows indicating the general flow pattern in figures 5 en 6. The results are described in more detail in the following sections for each river separately.

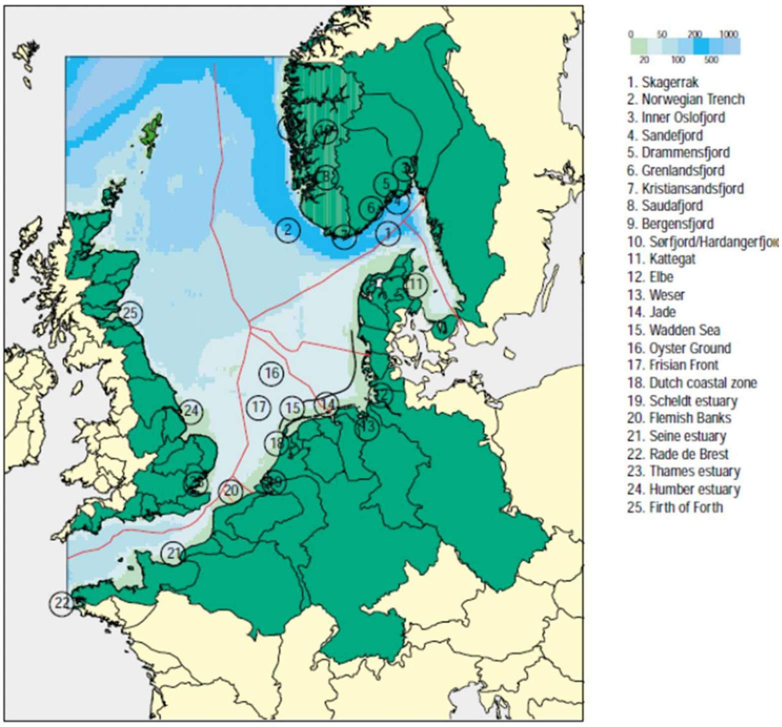


Figure 4 The North Sea with all catchment areas discharging in the North Sea (OSPAR).

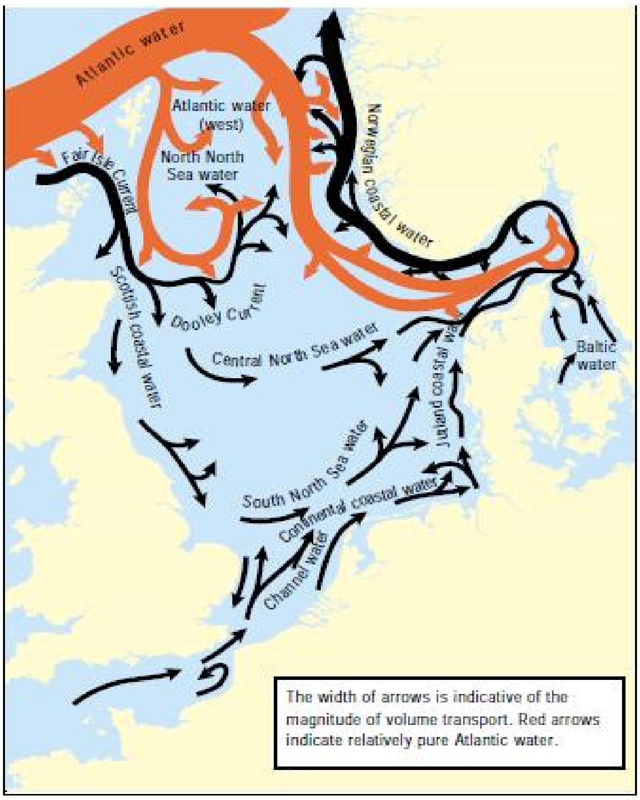


Figure 5 Schematic presentation of the residual water transport pattern in the North Sea (OSPAR).

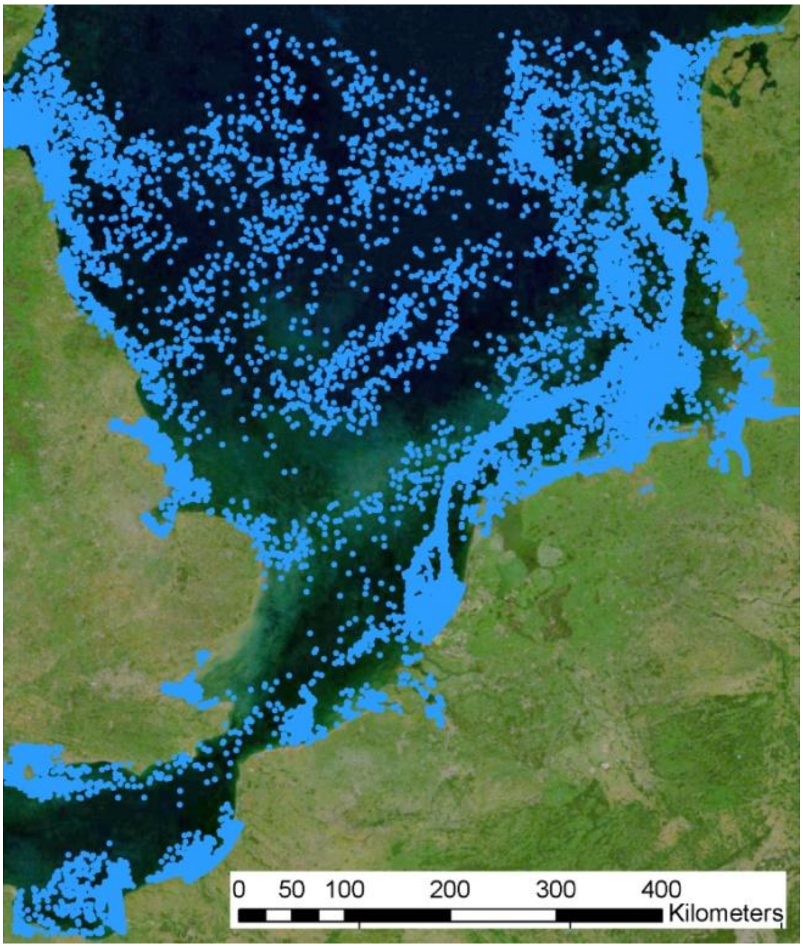


Figure 6 Simulation of floating plastic litter in the North Sea on 14 December 2008 prepared by F. Kleissen (Deltares).

Table 1 Characteristic data of several rivers discharging into the North Sea. Note: the data are rough estimates. Numbers in italic are based on extrapolation of data for other rivers.

River	**Catchment area**		**Average discharge fresh water**		**Population in catchment area**		**Macroplastic contribution**			
							Fine fraction		**Coarse fraction**	
	km^2	**%**	**1000 km^3/year**	**%**	**million**	**%**	**(m^3/year)**	**%**	**(m^3/year)**	**%**
Rhine	185,000	22	75	21	58	35	*500 - 5000*	*3 - 33*	*50 – 500*	*0.3 – 3.3*
Meuse	35,000	4	10	3	9	5	100 – 1000	1 – 7	10 – 100	0.1 – 0.7
Scheldt	21,000	2	5	1.4	7	4	*60 – 600*	*0.4 – 4*	10 – 100	0.1 – 0.7
Ems	18,000	2	2.5	< 1	3	2	*50 – 500*	*0.3 – 3.3*	*5 – 50*	*0 – 0.3*
All rivers discharging into the North Sea	840,0000	100	350	100	164	100	14.000	*93*	*1.000*	*7*

The data in Table 1 illustrates that the general characteristics are more or less similar for the catchment areas of the rivers Rhine, Meuse, Scheldt and Ems. These catchment areas lie in the same climate zone and are all densely populated. This means that they are comparable in terms of their litter contribution to the North Sea, even though the characteristics of their catchment areas differ in detail.

It should be stressed that the contribution of these rivers is presented in volumes (m^3). This measure was chosen due to the fact that our data, mainly from clean-ups, were presented in volumes rather than in weight. Therefore, interpretation of these volumes in terms of their contribution to the total amount of litter in the North Sea, which is expressed in weight, should be evaluated. This issue does not only hold for the present report, but also relates to an on-going discussion among experts on how to quantify the presence of plastic litter (number of items, volume, weight, etc.), which should be carefully considered in relation to an evaluation of monitoring data.

3.2 River Rhine

The data collection, based on data from clean-ups, on transport of plastic litter in the Rhine is incomplete but does demonstrate that plastic litter can be found in the whole stretch from Basel to Rotterdam and that plastic litter causes nuisance for the riparian population. Clean-ups by volunteers are organised frequently along the river Rhine including the main tributaries. However, the available field data are insufficient to quantify transport rates of plastic litter. Downstream of Dordrecht (Biesbosch) the harbours of Rotterdam will discharge an additional unknown volume of floating macro plastic litter to the North Sea.

3.3 River Meuse– coarse and fine fraction

The river Meuse upstream of the nature reserve Biesbosch carries the following estimated volumes of plastic litter, based on the data from the MosaPura project.

Coarse fraction (≥25 mm)

The estimated volume is 10 to 100 m^3/year in periods with average floods for the coarse fraction of floating macro plastic litter. The maximum concentrations of the coarse fraction of floating macro plastic litter are expected in the stretch Namur – Sambeek.

It seems that large plastic items that float at the water surface are prone to stick to vegetation on river flood plain, dykes and pile up against hydraulic structures, like sluices and hydropower stations. Items are often removed from these locations because they block water flow, damage dyke slopes, hamper the use of an area or decrease its aesthetic value. For the river Meuse, it is suspected that these larger items are removed or rapidly degrade to smaller particles, microplastics, since relatively small amounts of larger plastic items are only found in the tidal stretch of the river.

Fine fraction (5 – 24 mm)

The transport of the fine fraction is about 100 to 1000 m^3/year in periods with average floods. After an extreme flood these volumes will be considerably higher, because of the inundation of relatively high areas of a floodplain. The average travel time of the fine fraction and the microplastics to the North Sea is expected to be relatively short compared to the average travel time of the coarse fraction.

3.4 River Scheldt – coarse and fine fraction

The river Scheldt carries the following estimated volumes of plastic litter to the North Sea, based on data from clean-ups.

Coarse fraction (≥25 mm)

The Scheldt River discharges the coarse fraction of floating macro plastic litter into the North Sea with an estimated volume of about 10 to 100 m^3/year in periods with average floods and tides. After an extreme flood and extreme tides this volume might be higher. In addition, the Scheldt River discharges an unknown volume of suspended macro plastic litter with foil like shapes to the North Sea.

The maximum concentrations of the coarse fraction of floating macro plastic litter are expected in the stretch from the sluice Wintam near Rupelmonde to tidal flat Galgeschoor just downstream of Antwerp. Downstream of Antwerp the harbours of Terneuzen and Flushing will discharge an additional unknown volume floating macro plastic litter to the North Sea.

Fine fraction (5-24 mm)

The transport of the fine fraction of macro plastic litter might be much larger than the transport of the coarse fraction, similar as in the river Meuse.

4 Governance

The prevention of littering is laid down in regulations of parties on various levels. On an EU level there are several regulations in place such as the Waste Framework Directive and Port Reception Facility Directive. Additionally, OSPAR and the IMO both have regulations on waste management which are valid for the North Sea. On a regional scale, Regional Sea Conventions such as OSPAR and the Bucharest and Barcelona Convention develop regional action plans on marine litter. For the Rhine and partly for the Meuse and Scheldt there is an international regulation, the CDNI which should prevent the emission of litter and waste to the environment. In the Netherlands laws on littering and waste management are in place, both in the aquatic and terrestrial environment such as the Water Law (Waterwet) and Law on Environmental Governance (Wet Milieubeheer).
The removal of plastic litter in a river system is carried out by multi-jurisdictional land owners (for example nature conservation organisations, municipalities, water boards, national authorities and some private organisations).
Institutions such as the EU and River Commissions already facilitate discussions among member states to prevent the emission of waste and litter. On a national level however, the involvement of many different parties complicates the prevention and the systematic removal of litter in a river system. For example discussions with producers aim at a reduction of their emission of primary microplastics. Furthermore, due to lack of effective and harmonised laws and regulations focused on the prevention of litter in the environment, these instruments are insufficient to reduce the quantities of plastic litter in the considered river systems. Effective legislation would result in a more transparent and focused distribution of tasks.

5 Monitoring

Monitoring of plastics in the marine environment is conducted by OSPAR where plastic waste in the stomachs of northern fulmars, an abundant sea-bird in the North Sea, is used as an Ecological Quality Objective (EcoQO) to assess litter in the marine environment. OSPAR also developed a method to determine litter pollution on beaches. For microparticles, the assessment of small plastic particles is carried out on the water surface, in sediments and in biota in separate studies, but not under the umbrella of a wider monitoring program. Several studies have researched the possibilities of using sensors to assess waste in a more automated manner to reduce costs and optimise efficiency. So far these methods are still in the experimental stage and have not been widely adopted yet.

Apart from monitoring within OSPAR, no regular monitoring programs have been set up for assessing litter in the aquatic environment. Furthermore, standardized protocols for monitoring and analysis of litter are lacking, which complicates the comparison among different studies. However, for the marine environment such protocols are being developed in framework of the MSFD by the TSG Litter and monitoring programmes will be implemented in 2014. For the riverine environment regular monitoring programmes are lacking at present.

6 General conclusions

Based on this research it can be stated that the presence of (plastic) litter in the studied catchment areas is of high environmental and societal concern and is perceived as such by the general public. Regular clean-ups by volunteers have raised awareness about the pollution of the environment in the floodplains of the rivers Rhine, Meuse and Scheldt. The large yearly effort to remove debris with plastic litter from the dykes and the floodplain by river management organizations requires considerable budgets. The amount of available quantitative data for litter in Dutch rivers is limited and can mainly be found from sources that have not been scientifically validated. This means that research in this area depends strongly on estimations based on expert judgement and a few available data sources. On basis of the available data it can be roughly estimated that rivers discharging into the North Sea cause the inflow of about 50 % of all floating plastic litter in the North Sea and that the rivers Rhine, Meuse and Scheldt contribute about 15 % of all floating plastic litter.

7 Recommendations

A reduction of litter from land-based sources to the marine environment requires appropriate management actions based on up to date and in depth knowledge of transport of plastic litter in river systems. The current knowledge on litter in rivers is limited. It is therefore recommended that:

Recommendation 1. High quality data on macro plastic litter in rivers

- Set up a monitoring program
  Set up a monitoring program of the transport of macroplastics via rivers:
  – Systematic field surveys to measure the occurrence of macroplastics in freshwater systems. These surveys are part of a regular monitoring program and executed according to a standard data protocol concerning the transport of plastic litter in a river catchment, especially measurements and observations during floods. Furthermore, monitoring should include areas with low turbidity, since these areas and associated organisms are probably prone to the accumulation of plastics. Locations where plastic litter accumulates after a certain flood can be predicted using mathematical models. This should preferably be consistent with programs already in place for the marine environment and beaches, for example beach monitoring under OSPAR.
  – A program for special monitoring pilots focusing on the development of effective standard monitoring methods for field surveys, for example:
    - Monitoring of the transport of suspended plastic litter in a river,
    - Monitoring plastic litter transported as bed load in a river,
    - Monitoring the process of fouling with algae or,
    - Monitoring the effect of UV radiation of macroplastics in floodplains.

- Set up a European (international) database
  Set up a European (international) database on volumes, weights and types of retrieved plastic litter. This database should also include an inventory on costs and sources of plastic litter per river system. Analysis of such a database will support identification of specific sources e.g. sewage treatment plants. Contractors and volunteers in clean-ups should be able to add their data according to a standard data protocol in a separate section of the database. Research data could then be shared through European databases for each river catchment. This should be connected to existing databases for example RID database (OSPAR).

Recommendation 2: Research on microplastic litter in rivers

- To conduct systematic field surveys to measure the occurrence of microplastics in freshwater systems.

Other recommendations:

Increase understanding of sources and transport of plastic litter in rivers

- Set up an international inventory of methods to attribute collected plastic litter to a certain source (such as microplastics in effluents from sewage treatment plants).
  The application of selected methods will increase the understanding of the sources and transport of plastic litter in rivers.

Co-operation and regulations

- Exchange views and experiences on measures to reduce the transport of plastic litter in rivers. This should lead to the introduction of effective and harmonized laws and regulations regarding litter in a river system.
- Intensify the international co-operation in research and communication and dissemination to the general public.

Research

- To study the different sources of plastic litter. For example to estimate the amounts of plastics run-off from sludge dispersed for agricultural purposes, an application that is still used in neighbouring countries, and the contribution of geotextiles in floodplain roads, dyke protection and hydraulic structures.
- To study the effects of plastic litter on organisms living in rivers.
- To estimate the contribution of different countries to the total amount and type of litter in Dutch rivers and to analyse their different approaches.
- To study the options for monetary systems for individuals and industries to recover plastics, such as deposit legislation.