Deltares
Enabling Delta Life

Plastic litter in the rivers Rhine, Meuse and Scheldt

Contribution to plastic waste in the North Sea

Final draft 2013

Deltares

Plastic litter in the rivers Rhine, Meuse and Scheldt

Contribution to plastic waste in the North Sea

Final draft 2013

M. van der Wal
M. van der Meulen
E. Roex
Y. Wolthuis
G. Tweehuijsen
D. Vethaak

1205955-006

Deltares

Title
Plastic litter in the rivers Rhine, Meuse and Scheldt Final draft 2013

Client	Project	Reference	Pages
Rijkswaterstaat, Dutch PublicWorks Department	1205955-006	1205955-006-ZWS-0006	125

Keywords
Rivers, litter, debris, Scheldt River, Meuse River, Rhine River, plastic litter, Marine Strategy Framework Directive

Summary
The unique properties and societal benefits of plastics have led to an increased global plastic consumption that results in growing accumulation of end-of-life plastics. Plastics discarded off improperly end up in the environment, both land and water, where they may be transported to the seas and oceans. Rivers are transportation pathways that carry litter into the seas and oceans.

The general picture of plastic litter in the Rhine, Meuse and Scheldt rivers is complex partly because many different organizations are involved and data on plastic litter are not collected systematically. An overview has been prepared of available data and data gaps. The data were analysed and used for a preliminary assessment of the contribution by Rhine, Meuse and Scheldt to the plastic waste in the North Sea. Based on the limited data on removal of litter by contractors and collection of litter by volunteers in flood plains, measurements of transported litter indicate that about 15,000 m^3 macroplastic litter entered the North Sea yearly in the period 2000 to 2012. In that period no extreme floods occurred. The rivers Rhine, Meuse, Scheldt and Ems discharge 800 to 8,000 and on average 4,500 m^3/year macroplastic litter into the North Sea. Preliminary measurements in the river Meuse indicate that around 20 % of the plastic litter is transported in suspension and 80 % floating. This figure however by far reflects the true magnitude of plastic waste entering the North Sea. For example, the harbours Rotterdam, IJmuiden contribute most likely also to the plastic waste in the Nord Sea and their contribution is not included in this number. In addition micro plastic particles enter the North Sea and no information is available about the total volume of these particles transported in rivers.
Modelling of the transport of litter in rivers increases the understanding of the physical phenomena and that will contribute to the set up of a monitoring program. Recommendations are formulated concerning the setup of a monitoring program and an international database for monitoring data.

References
1205955.006 and minutes of meeting.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
1	May 2013	M. van der Wal		F Kleissen		S. Tatman	

State

Deltares

Title
Plastic litter in the rivers Rhine, Meuse and Scheldt
Final draft 2013

Client	**Project**	**Reference**	**Pages**
Rijkswaterstaat, Dutch PublicWorks Department	1205955-006	1205955-006-ZWS-0006	125

This is a Final draft report.

Contents

1 Summary

1.1 Introduction

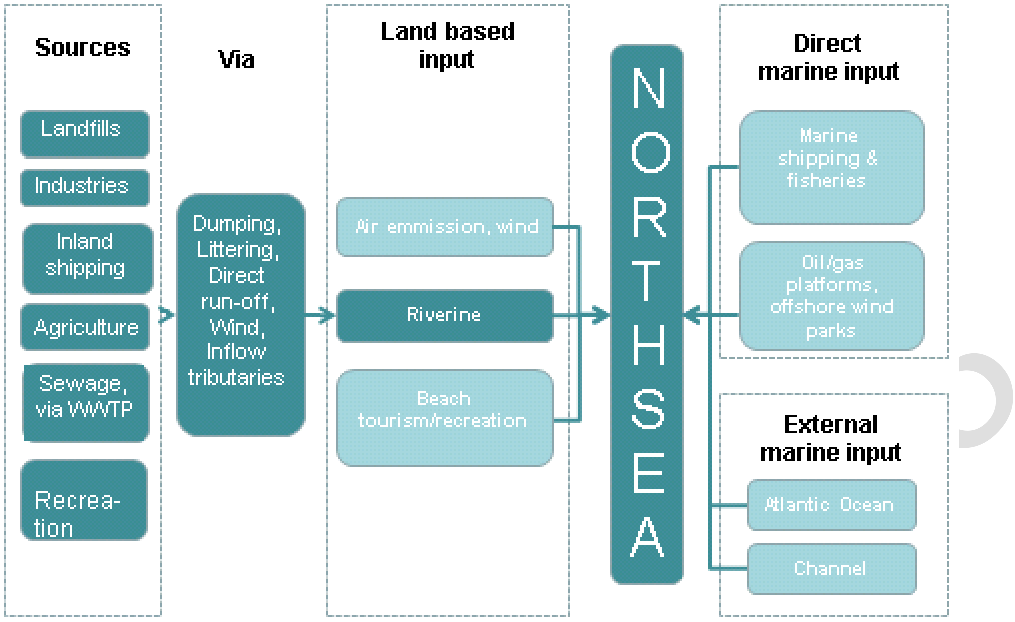
The Marine Strategy Framework Directive (MSFD) installed to ensure Good Environmental Status (GES) by 2020 includes the descriptor ‘Marine Litter’ (descriptor 10). For freshwater, one of the main policy instruments is the Water Framework Directive (WFD), which does not include litter in determining ecological 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 litter problem in their rivers and the contribution of these rivers to litter in the North Sea.

1.2 Definitions, sources and pathways

In this study the focus lies on plastic litter due to their 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 that results in 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.



Items on a dark blue background are subject of this study
Figure 1.1 : Schematisation of sources and pathways of litter to the North Sea.

The sources mentioned in figure 1.1 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 is part of different countries, transboundary litter is transported from neighbouring countries.

1.3 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 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 can be stated 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.

1.4 Transport processes of plastic litter

1.4.1 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 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 at the water surface, those with a higher density than water, sinks and eventually becomes part of the bed load.

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, which occur 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 the litter. A pathway ends temporarily at a bank, in vegetation topping above the water level or at hydraulic structures (Figure 1.2). 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.

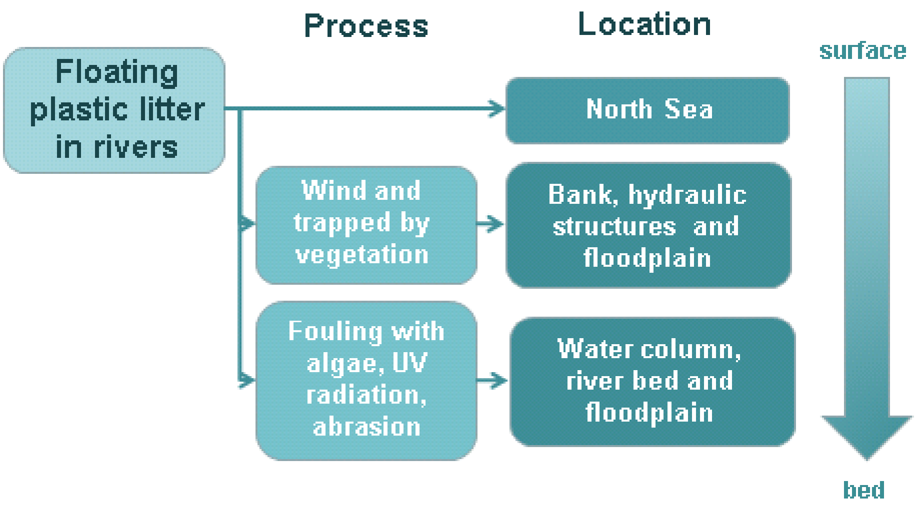


Figure 1.2 Scheme for the transport of floating plastic litter in rivers

1.4.2 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 1.3. Bank of the river Meuse near Borgharen, 10 January 2011 (courtesy Mrs Wolthuis)

1.4.3 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.

1.4.4 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 period of <u>presence</u> 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 we estimate that these rivers contribute 0.30 * 15,000 = 4,500 m^3 macroplastics/year.

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 4 en 5. The results are described in more detail in the following sections for each river separately.

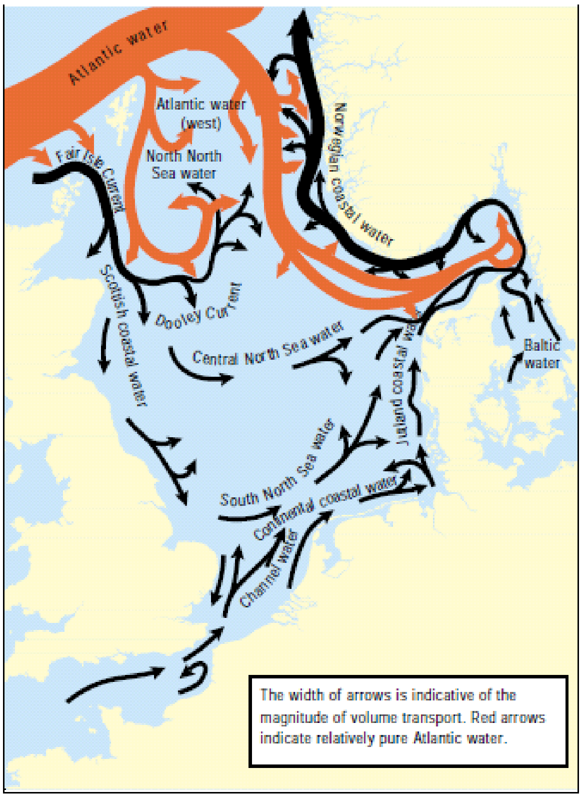


Figure 1.4 Schematic presentation of the residual water transport pattern in the North Sea (OSPAR)

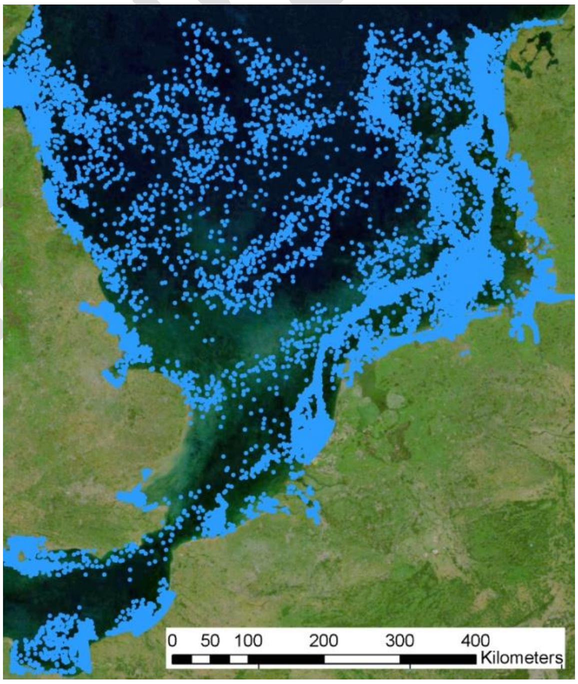


Figure 1.5 Simulation of floating plastic litter in the North Sea on 14 December prepared by F. Kleissen (Deltares)

Table 1.1 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**			
	km^2	**%**	**1000 km^3/year**	**%**	**million**	**%**	**Fine fraction (m^3/year)**	**%**	**Coarse fraction (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	840,000	100	350	100	164	100	14.000	*93*	*1.000*	*7*

The data in Table 1illustrates that the selected 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.

1.4.5 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.

1.4.6 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 up to Dordrecht.

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 travel time of the fine fraction and the microplastics is expected to be relatively short compared to the travel time of the coarse fraction.

1.4.7 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 River Scheldtdischarges 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 River Scheldtdischarges 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.

1.4.8 River Rhine, Meuse and Scheldt- microplastics (< 5 mm)

Using data from 2010 on amounts of waste water ($2*10^9$ m^3) and a concentration of 10 particles microplastic per liter effluent on average, it can be estimated that a 100 million particles microplastic enter the Dutch surface waters every day. Based on the population living in the Rhine and Meuse basins, respectively 6.5 and 3.5 million inhabitants the amount of microplastics used results in 15,6 kg/day for the Rhine basin and 8,4 kg/day for the Meuse basin.

1.5 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.

1.6 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 monitoring programmes will be implemented in framework of the MSFD in 2014. For the riverine environment regular monitoring programmes are lacking.

1.7 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 not scientifically validated sources. 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 these floating plastic litter.

1.8 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

- <u>Set up a monitoring program</u>

  Set up a monitoring program of the transport of macroplastics via rivers:

  – Systematic field surveys to measure the occurrence of macroplastics in freshwater systems. A regular monitoring program concerning the transport of plastic litter in a river catchment, especially measurements and observations during floods. 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.

<u>Set up a European (international) database</u>

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 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 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).

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 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 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.

2 Introduction

The unique properties and societal benefits of plastics have led to an increased global plastic consumption that results in growing accumulation of end-of-life plastics. Plastics discarded off improperly end up in the environment, both land and water, where they may be transported to the seas and oceans. Rivers are transport pathways that carry litter into the seas and oceans.

The general picture of plastic litter in the rivers Scheldt, Meuse and Rhine (figure 3.1) is complex partly because many different organizations are involved and data on plastic litter are not collected systematically (Paassen, 2010). This desk study aims to prepare an overview of all available data and to analyse these data to assess the contribution by the rivers Scheldt, Meuse and Rhine to the plastic waste in the North Sea.

The following aspects of litter and plastic pollution in rivers are investigated:

- Importance of floating debris and litter in the North Sea. The amount of floating debris
  - The negative effects of floating debris.

- The contribution by rivers Rhine and Meuse to the floating litter in the North Sea. These rivers flow via the Dutch delta to the North Sea. The catchment areas of these rivers , total about 220.000 km^2 form a significant part of all catchment areas discharging in the North Sea, 840,000 km^2 see figure 3.1
  - The volume and composition of floating debris
  - The transport process in rivers of floating debris,
  - Legislation and regulations.

- The main sources of floating litter in rivers Scheldt, Meuse and Rhine and their location in the catchment areas, see figures 3.1 and 3.2. Each river has its own characteristics, even though these catchment areas border each other.

- The data available and the “missing” data. In the past plastic litter was considered as an inert material and therefore no monitoring was set up for plastic litter in rivers, nor in the marine environment. Recently new insight has changed this view and the environmental risks of plastic litter are more and more recognized.

- Proposal for a monitoring program of plastic litter in rivers and the prediction of the locations as banks and vegetation where floating debris can be expected to accumulate after a certain flood.

The Ems River is downstream of Emden a tidal estuary with the border between Germany and the Netherlands in the main channel. This river is for the plastic pollution in the Dutch delta of minor importance. Therefore, and partly also due to other constraints the litter and debris, transport is not described for the Ems River.

•

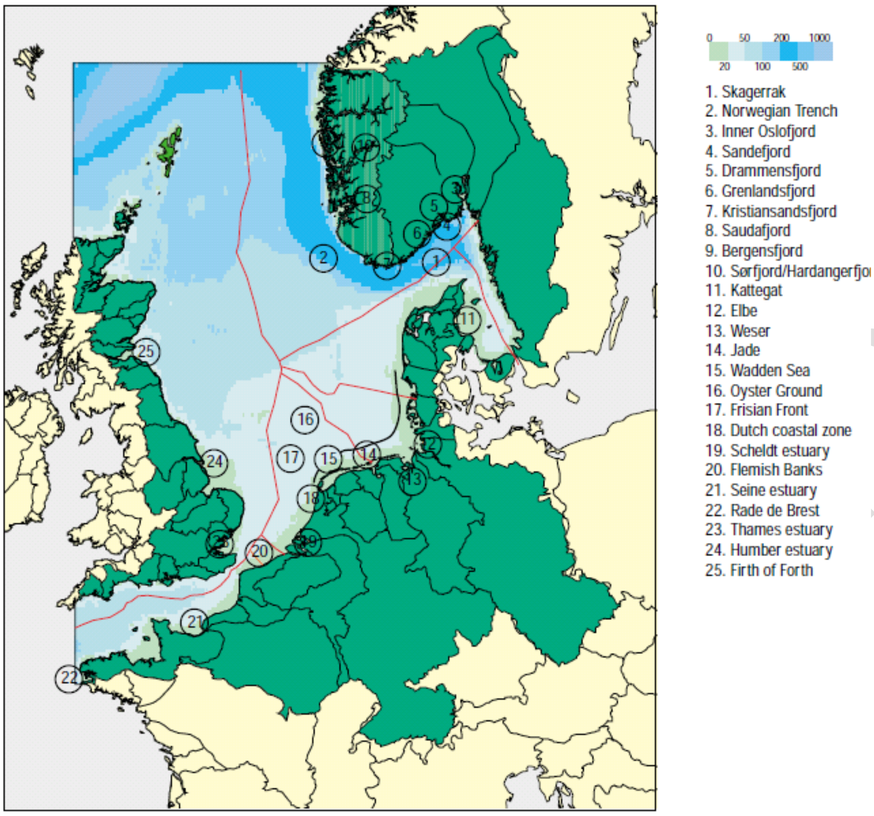


Figure 3.1 The North Sea with all catchment areas discharging in the North Sea.

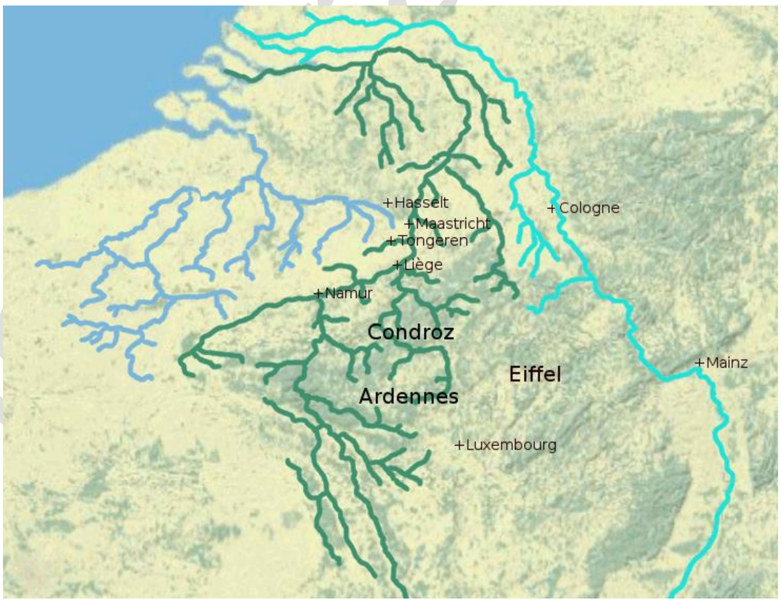


Figure 3.2 A sketchy map of the Scheldt, Meuse and Rhine rivers and some of their tributaries (Wikipedia, A. Lancaster)

The word debris is interpreted in a broad sense within this report; however, the focus lies on plastics due to its longevity and the fact that plastic litter is currently seen as one of the emerging environmental risks. In alluvial rivers in deltas debris contains mainly remains of vegetation (such as stems, trunks, roots and leaves) and a small fraction plastic litter and other litter (floating items composed of metal, glass or wood). The scope of this report includes plastics from macro- to micro size. For the marine environment the report focuses on the entire North Sea with special reference to the Dutch Continental Shelf. For the chapters of the report referring to rivers the focus lies on the rivers Scheldt, Meuse and Rhine. The delta of these rivers lies within the Netherlands where they discharge into the North Sea. The primary function of an alluvial river is the conveyance of water and sediment. The conveyance of plastic debris is a secondary function. Three modes of transport are distinguished: floating, in suspension and as bed load. This is in analogy with the transport of sediment in an alluvial river in a delta.

The Dutch Ministry of Infrastructure and Environment (I&M) is acknowledged for sponsoring this project. This desk study was performed by M. van der Wal, M. van der Meulen, D. Vethaak, E. Roex (all from Deltares), Y. Wolthuis (ISI) and G. Tweehuijsen.
The project was supervised by S. van de Graaf, B. Bellert, R. van Dokkum (all from Rijkswaterstaat, Waterdienst) and L. Oosterbaan (Rijkswaterstaat, Directorate North Sea) and their contribution are gratefully acknowledged.

3 Background and significance of floating litter and other debris in the North Sea

3.1.1 Sources

Determining the source of marine debris is relatively easy up to a certain size, shape, colour, presence of labels and other features such as polymer type. The specific origin of a waste item however is hard to determine since items are often degraded into unrecognizable fragments. For microplastics this is virtually impossible since all particles look similar under a microscope. Although microplastics can be quantified according to polymer type, specific features are usually lacking, which makes it difficult to trace back their source. An exception to this may be nylon or acryl fibres originating from synthetic clothes in washing machines and fishing ropes and nets (filament netting).

The principle sources of macro debris are thought to be fishing, shipping (Derraik 2002; UNEP 2009) and riverine/terrestrial sources (Ryan et al. 2009). For microplastics the main sources are degradation of larger plastic waste (secondary microplastics), and consumer products, industrial applications, spillage from preproduction pellets, and waste water treatment effluent (primary microplastics).

It is estimated that the total input of marine litter into oceans on a global scale is approximately 6.4 million tonnes per year, out of which 5.6 million tonnes is attributed to the shipping industry (Ardena Milo, 2001). Fishermen loose gear on a daily basis, mainly because their nets get caught behind shipwrecks or other hard materials on the seafloor. There are no data available for the Netherlands specifically, however, in neighbouring countries such as the UK, all coastal fisheries combined loose about 35 km of net per boat per year (FAO, 2009). For microplastics the main sources are degradation of larger plastic waste (secondary microplastics), and consumer products, industrial applications, spillage from preproduction pellets, and waste water treatment effluent (primary microplastics).

UNEP published an overview for the debris that floats on the surface (see figure 2.1) demonstrating that sources of debris are both point- and non-point sources and are present on land, in coastal areas and off-shore.

Table 1. Types and Sources of Floatable Debris

Source	Examples of Debris Released
Storm Water Discharges	Street litter (e.g., cigarette butts, filters, and filter elements), medical items (i.e., syringes), resin pellets, food packaging, beverage containers, and other material from storm drains, ditches, or runoff
Combined Sewer Overflows	Street litter, sewage-related items (condoms, tampons, applicators), medical items (i.e., syringes), resin pellets, and other material from storm drains, ditches, or runoff
Beachgoers and Other Nonpoint Sources	Food packaging, beverage containers, cigarette butts, toys, sewage, pieces of wood and siding from construction projects, and trash (e.g., beverage containers, food packaging) left behind by workers in forestry, agriculture, construction, and mining
Ships and Other Vessels	Fishing equipment (e.g., nets, lures, lines, bait boxes, ropes, and rods), strapping bands, light sticks (used by fishermen to light up fishing lines and recreational divers), plastic salt bags, galley wastes, household trash, plastic bags and sheeting, and beverage yokes (six pack rings for beverage containers)
Solid Waste Disposal and Landfills	Materials such as garbage and medical waste
Offshore Mineral and Oil and Gas Exploration	Data-recording tape, plastic drill pipe thread protectors, hard hats, gloves, and 55-gallon drums
Industrial Activities	Plastic pellets and other materials
Illegal Dumping or Littering	Food packaging, beverage containers, cigarette butts, appliances, electronics, and ocean and street litter

Figure 2.1 An overview of the types and sources of floatable debris (UNEP, 2009)

More background information on litter in the marine environment can be found in Appendix A of this report.

3.1.2 Effects of debris on marine biota

For plastics, the effects depend on the size of the particles present in the marine environment. These effects are mainly entanglement and ingestion (see appendix A) which can have effects throughout the food chain.,Other effects have also been documented. For example, litter sinking to the sea floor may cause anoxia to the underlying sediment, thereby affecting the biogeochemistry and benthos. Furthermore, litter is thought to be a vehicle for alien species as well as a substrate for sessile biota (Bergmann & Klages, 2012, in press).

3.1.3 Social impacts of marine litter and impacts on health and safety

Even though social impacts of marine litter are to be expected in terms of quality of life, reduced recreation, loss of aesthetic value and loss of non-value, few studies have investigated at which level marine litter leads to the occurrence of these impacts (Cheshire et al., 2009 from KIMO, 2010). The impacts on health and safety include navigational hazards, injuries to recreational users and the leaching of poisonous chemicals (KIMO, 2010).
Ingestion of microplastics and release of plastic additives are a threat to marine biota. They can potentially accumulate in food chains and pose a health threat to human consumers of fish and shell fish, see appendix A.

3.1.4 Economic impacts of marine litter

The economic impacts of marine litter are described in appendix A. A study on the economic impacts of marine litter was conducted by KIMO in 2010. The research looked at the whole of the Northeast Atlantic, including the Netherlands.

Approximately two thirds of the municipalities cooperated with external parties in clean ups on their beaches. The majority of the municipalities surveyed used a combination of mechanical and manual methods for cleaning up the beach.

Table 3.2 Estimated costs of marine litter for the Netherlands, Belgium and United Kingdom

Country	**Total cost of beach clean-up to municipalities (€)**	**Average cost per municipality per year (€)**	**# of municipalities participated (-)**	**Average stretch cleaned per municipality (km)**	**Quantity removed (ton)**
Netherlands and Belgium	10,400,000	226,541	10	6.2	724 (in 6 municipalities)
UK (including Scotland)	18,000,000	145,587	31	17.5	21,757 (in 19 municipalities)

The yearly average costs for the removal of marine litter on beaches are higher in the Netherlands than in the UK, even though the average stretch cleaned is smaller. For other countries around the North Sea only a few responses were gathered, therefore they were not taken into account in this research.

To study the economic costs of marine litter to other organisations, KIMO focused on the United Kingdom (UK). Even though the litter problem is likely to be different in the UK and in the Netherlands, values for the UK and Scotland are taken as an estimate for those of the Netherlands, see appendix A.

3.1.5 Legislation on litter and management of litter

An extensive description is presented of international aspects of legislation on marine and riverine litter in appendix B.

4 The transport of plastic litter in Meuse, Scheldt and Rhine Rivers

4.1 Introduction

The rivers Meuse, Scheldt and Rhine form the Dutch delta and discharge into the North Sea. The river basin of the River Meusecovers parts of France, Belgium and the Netherlands. The river basin of the river Rhine comprises parts of Switzerland, France, Luxembourg, Germany and the Netherlands. The source of the River Scheldtis in the Northern part of France, in addition a large area of Flanders discharges into the middle stretch of the Scheldt River. The most downstream stretches of these rivers pass through the Dutch delta. The natural width of these rivers has been reduced in most downstream stretches by dykes and other river training works. These dykes have a protection layer against flow and wave attack. Typically this protection layer consists of a base of rip rap and an upper part of grass on a clay layer.

A network-organization of about 100 Dutch municipalities along the main Dutch rivers (Rhine, Meuse and Scheldt) intends to pay particular attention to the increasing hindrance by floating litter.

This desk study focusses on the presence and transport of plastic litter and the contribution of these stretches to the plastic litter pollution in the North Sea. The relevant aspects of the presence and transport of plastic litter are described for in the river Meuse, river Rhine and river Scheldt in respectively Section 4.2, 4.3 and 4.4.

4.2 Rhine River

4.2.1 Introduction

The River Rhineflows from the Swiss Alps mainly through Germany and the Netherlands where it discharges into the North Sea. The total length of the River Rhineis 1320 km and the mean discharge in Lobith is about 2,300 m^3/s. The total catchment area including all tributaries covers 185,000 km^2 and a population of about 50 million inhabitants. The main areas with high population density are Karlsruhe, Koln, Ruhr area (Duisburg), Arnhem/Nijmegen and Rotterdam.

In 1993 and 1995 extreme floods occurred with maximum discharges at Lobith of 11,100 m^3/s in 1993 with a statistical return period of 30 years and 12,060 m^3/s in 1995 with a statistical return period of 80 years (TAW, 1995).

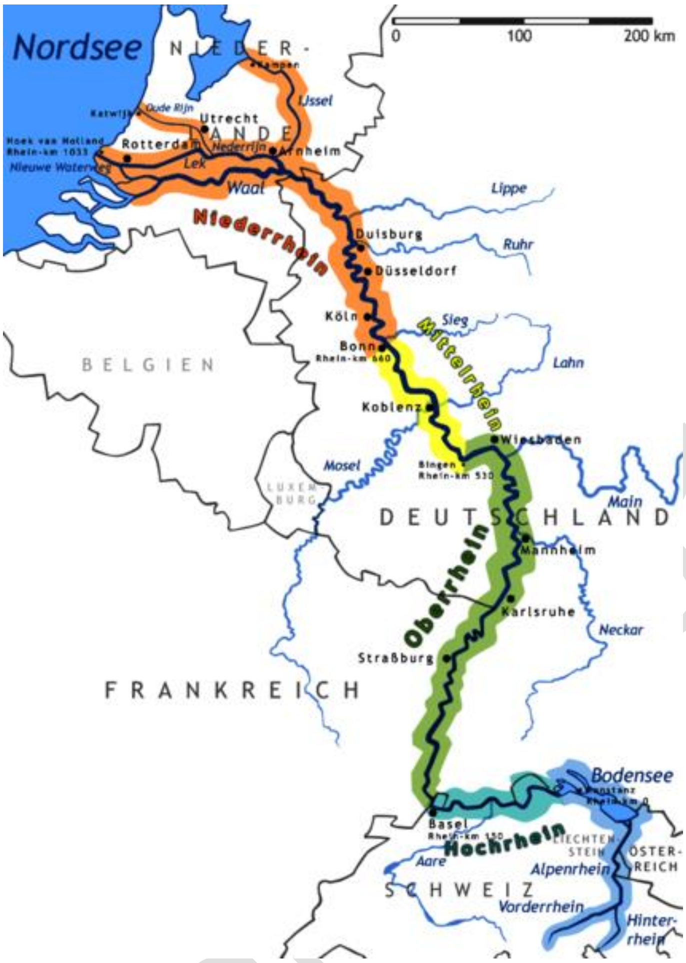


Figure 4.7 River Rhinebasin with the main tributaries

4.2.2 Collection of floating debris

Wind and waves combined with floating debris can damage the protection layer on the outer slopes of dykes during floods. Along the main Dutch rivers this surface layer exists of a clay layer covered by grass in most cases (TAW. 1995).

Examples

In the Lek River (branch of the Rhine River) the outer slope of the dyke the combination of waves and floating debris caused a hole of 15 m long, 2 m wide and 0.5 m deep during the February 1995 flood. This hole was filled as part of an emergency action with sand bags and a cover of geotextile and again loaded with sand bags.

The combination of floating debris and waves caused damages on a stretch of about 2 km in a dyke within the management area of waterboard IJsselland-Baakse Beek (0.25 tot 0.75 m2 in a cross section of a dyke) in the IJssel River on February 1995. Also along the IJssel River but within the management area of the waterboard De Berkel large amounts of floating debris were observed and on several places minor damages were filled with sand bags during the same flood. Along the dykes of the same river but within the management area of the waterboard Salland aan de IJssel more damages to the outer slope could be prevented by moving large pieces of floating debris to a higher level on the dyke. These examples are described in a TAW report (TAW, 1995).

In Lobith the water level reached a maximum level of NAP + 15.15 m during the 2011 flood. During that flood the waterboard Rivierenland reported the following damages by floating debris (ENW, 2011)

Figure … Collection of floating debris by a contractor commissioned by the waterboard Rivierenland, 2010 (photo waterboard Rivierenland)

Figure.. View from the dyke along the Waal branch of the River Rhinenear Ochten,during an extreme flood with the flood plains inundated, 1 February, 1995 (Rijkswaterstaat beeldbank)

Figure … A corner near a dyke of the Waal branch of the River Rhinenear Druten, January 2010

Litter in the floodplain is not only removed by contractors and organized groups of volunteers, but sometimes also by individual persons living near a river. A special example is Mr Verkaart who lives temporarily in the flood plain of the Waal branch near Druten, see figure .. The processing of the collected litter by him is not known (De Gelderlander, 30 juli 2010).

Figure .. Mr Verkaart with collected plastic litter (De Gelderlander, 30 juli 2010)

Measures

During a flood dyke inspectors move the large parts of floating debris accumulated against a dyke to a higher level on the dyke's outer slope. After a flood the waterboards organize a clean-up of debris on dyke slopes. Rijkswaterstaat Oost Nederland assigns contracts to contractors to remove debris from the floodplain.

The Waterboard Rivierenland assigns contracts to contractors to remove debris piled up against the outer slope of their dykes along the Waal, PannerdensKanaal en Neder-Rijn after a flood (for example after the flood of 2011). This Waterboard does not collect data on the type and the size of the debris (personal communication). The reason for collecting floating debris from the dyke slopes is that the grass protection layer will loose its protective function after the grass has died under the debris.

Figure 3.8 Example of floating debris accumulated against a dyke during flood

Volunteers

Individual volunteers irregularly collect waste from the floodplain. Normally they make piles of debris in the flood plain and do not completely remove all the debris from a floodplain.

Organised groups of volunteers clean the floodplain annually on a specific day. For example, a local group of members of a political party focused on the living conditions of animals organised a cleaning action of a part of the bank of the river Waal because horses in these nature reserves get wounded by eating parts of debris.

Also classes of primary schools clean the floodplain in the framework of a special educational project to learn about the environment.

In general the collected debris is not sorted and no information is documented on the total volume or the total weight of the collected debris. Only in very special cases lists are filled in as proposed by OSPAR as done by J. van Paassen (2010). She investigated only 5 m length of an edge of floated debris with a width of about 3 m in the Waal River. She found 50 items at a surface of 15 m^2 after the flood of 2010.

The foundation ARK cleaned a river bank over a length of 500 m and found 1700 pieces, this corresponds to around 350 pieces over a length of 100 m (ARK internet site).

4.2.3 Waste from inland ships

The collection of waste from vessels sailing on the River Rhineis organised in a treaty (2002). The main part of that waste is liquids as oil, but part C deals with waste from households on vessels.

Three guiding principles are applied:

- Aim to reduce the waste load on rivers,
- Prohibition on discharging waste in a river
- Polluter pays for discharging waste.

The organisation of the collection of this type of waste varies from country to country.(Koopmans, 2009). The Netherlands proposes international standardisation of the collection of this type of waste.

The Water Police on the Waal branch is more or less satisfied with the collection of household waste from skippers (personal communication).

Figure IJssel near during flood January 2013 (Y. Huismans)

4.3 Meuse River

4.3.1 Introduction

Geography

The River Meuserising at Pouilly on the Langres Plateau in France and flowing generally northward for 950 km through Belgium and the Netherlands to the North Sea. In the French part, the river has cut a steep-sided, sometimes deep valley between Saint-Mihiel and Verdun, and beyond Charleville-Mézières it meanders through the Ardennes region in a narrow valley. Entering Belgium at Givet, it continues northward to Namur, where it is joined on the left (west) bank by the Sambre River and then turns eastward to Liège. At Liège it is deep and narrow and lies about 137 meters below the plateau tops. The river turns north in a wider valley. From Venlo (Netherlands) the width of valley narrows up by dykes to the tidal estuary from Gorinchem to Hoek of Holland via the Nieuwe Waterweg and the Haringvliet where the River Meusedischarges into the North Sea, see map in figure 4.1. The main urbanized centers in the lower Meuse catchment are Namur with 110,000 inhabitants, Liège with 200,000 inhabitants and Maastricht with 120,000 inhabitants, in total 430,000 inhabitants. The Meuse catchment area is about 35,000 km2 with a population of 9 million (see. http://www.riwa-maas.org/nc/maas-drinkwater/stroomgebied.html).

Floods

The rainfall in the catchment feed the floods in the River Meuseresulting in sharp rise and fall of the water level and a short duration of a flood if compared to the floods in the Rhine River. In 1993 and 1995 extreme floods occurred with maximum discharges at Borgharen of 3,120 m^3/s in 1993 with a statistical return period of 150 years and 2,861 m^3/s in 1995 with a statistical return period of 100 years according to the analysis of the Boertien Commission (TAW, 1995) figure 3.1. In 2011 the maximum discharge was around 2100 m^3/s, figure 3.2

Figure 3.1 Map of the Meuse catchment

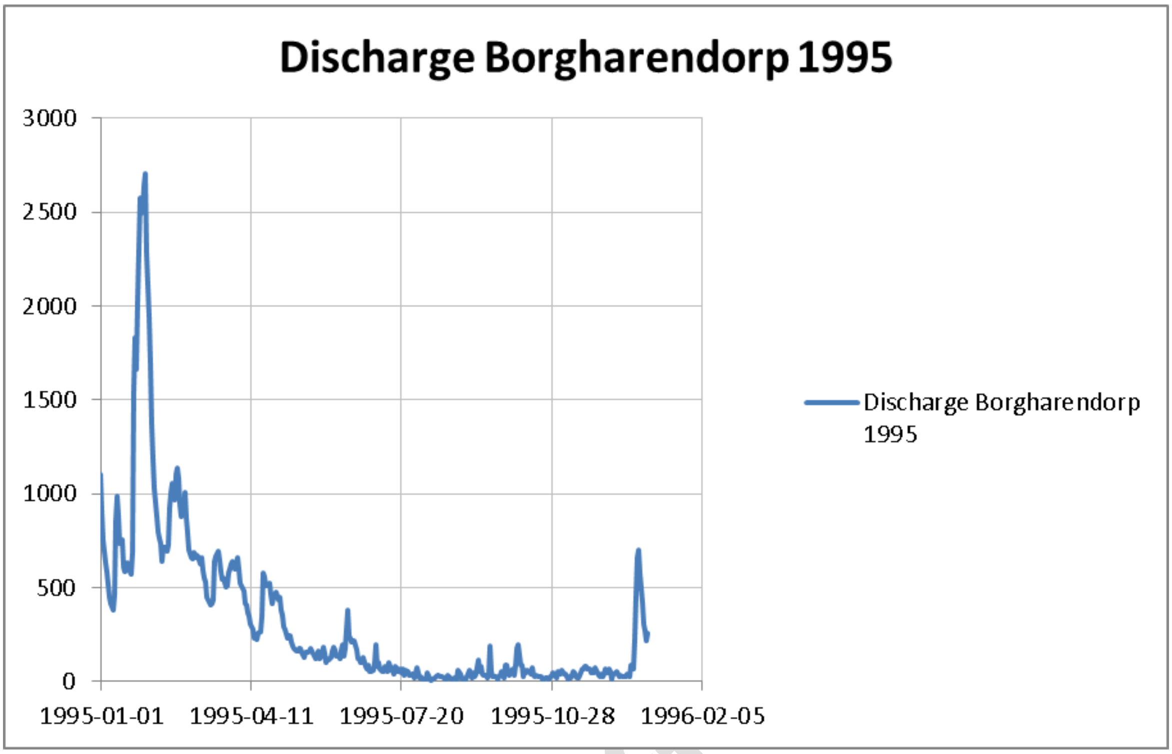


Figure 3.2 Discharge of the River Meusein Borgharen Dorp in 1995

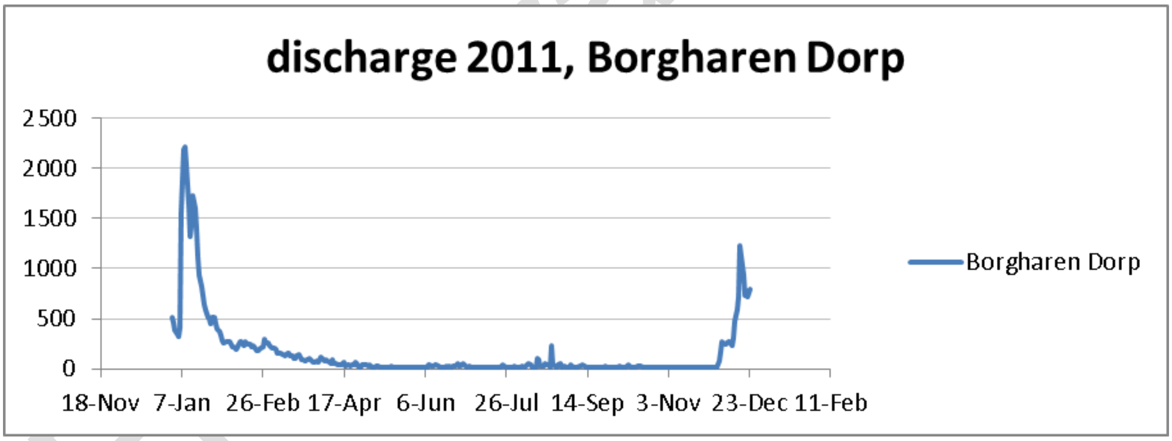


Figure 3.3 Discharge of the River Meusein Borgharen Dorp in 2011

The average discharge in the Meuse downstream of Maastricht is about 240 m^3/s. In dry periods the discharge is often very low.

General

The organization of removal of litter and debris in the floodplain of the River Meuseis described briefly in Paragraph 4.2.2. Further in this section two aspects are discussed regarding the removal of debris and litter from the Meuse floodplain: the costs involved and the amount of removed debris and litter (Paragraphs4.2.3 and 4.2.4). The available data is incomplete and lack a systematic pattern. Therefore several assumptions were made to sketch an overall picture of plastic litter in the Meuse basin

4.3.2 Organisation and management plan

International Meuse Commission

Part of the Meuse Treaty (Treaty of Ghent) is the installation of the International Meuse Commission (IMC) in 2002. This treaty aims at a sustainable and integral water management in the Meuse basin. This treaty was enforced in 2006. Presently the IMC does not officially recognise the issue of plastic litter although some awareness raising has been done by amongst others the Dutch Ministry of Infrastructure and Environment executive member of the IMC (personal communication 2012). They will be more likely to address the issue whenever it is integrated as a descriptor in the WFD as contribution to the reductions required within the MSFD.

Dutch national and local level

Every land owner is obliged to remove waste from his land according to the Law Environmental Governance or Wet Milieubeheer, Chapter 10 (Valkman, 2012). This also includes the removal of deposited debris and litter that was transported and deposited by a river during flood.

Rijkswaterstaat is the owner of major parts of the floodplain and this organization removes the debris and litter to improve the safety of navigation and the safety of their hydraulic structures (including dykes). The national plan for the maintenance of the national waterways called Beheer- en Ontwikkelplan voor de Rijkswateren 2010 – 2015 (BPRW) provides the frame work for an update of the local guidelines for the removal of litter (Valkman, 2012). In the guideline prepared for Rijkswaterstaat (Valkman, 2012) the tasks and responsibilities are described of municipalities, water boards, nature organizations and Rijkswaterstaat in the process of detection, collection and transport of litter and debris in the river floodplain. Removal of debris and litter can be divided in three steps; collection, transportation and processing of debris and litter to prepare it for a practical application. The removal of litter, waste dumping's and debris in a floodplain are included partly in the regular maintenance schedule and also in a two yearly cleaning-up of a 15 m wide strip along the bank or during a flood period in a weekly cleaning-up around the hydraulic structures owned by Rijkswaterstaat (Rijkswaterstaat, 2012).

The following waterboards are involved in the removal of debris and litter from the River Meusefloodplain:

- Water boards Roer en Overmaas andPeel en Maasvallei, both in province Limburg
  Water boards Aa en Maas and Brabantse Delta, both in province Noord Brabant
- Waterboard Rivierenland in province Gelderland
  Water board Zuidhollandse Eilanden in province Zuid Holland and
- NV De Scheepvaart in Belgium

.

In general, Water boards assign contracts to contractors for the cleaning-up activities in their management areas (owned and areas that a waterboard maintains). It is mentioned that the waterboard Roer- en Overmaas is very active in the removal of debris and litter in their management area.

Nature conservation organizations as Limburgs Landschap maintain large areas in the Meuse floodplain. These organizations take care of the removal of litter and dumping's of litter from their areas and they often organize clean-ups with volunteers in addition to smaller clean ups by their own staff.

The Foundation Nederland Schoon, Rijkswaterstaat and Natuurmonumenten cooperate in the project Maasschoon to celebrate in a special way the annually anniversary of a countrywide cleaning day of the environment. http://www.maasschoon.nu/index.html This cooperation is ongoing. The foundation Reinwater cooperates with foundation ARK, Rijkswaterstaat and the Waterboard Roer en Overmaas in the project Schone Maas. That project receives a subsidy by the Ministry VROM. The main goal of this cooperation is improvement of the water quality of the River Meuseby reducing emissions of chemicals widely used in agriculture.

4.3.3 Cost for removal debris

The reliability of the data used in this study with respect to cost of the removal of litter and debris is unsatisfactory, because both the information on the actions paid by the budget and the financial information are often incomplete. The preliminary analysis of the data in appendix A results in the following tendencies:

- The cost of removal of debris and litter in the Meuse valley seems to depend strongly on the maximum discharge during floods. Since the higher volumes are mainly collected from the floodplains and disposal is paid for by Rijkswaterstaat during the peak period between March 1st and May 1st each year. The regular removal of debris is procured at a service level standard fee.
- The cost of removal of debris and litter ranges from 100 to 200 euro/ton in 2011 including time spent by the staff of the waterboard. It is estimated from photographs that 10 to 20 % of waste consist of plastic litter.
- Rijkswaterstaat Limburg spent on average euro 850,000 per year on the removal of floating debris from the Meuse flood plains by contractors. A water board spent on average euro 150.000 per year on the removal of floating debris by contractors from their management area.
- In addition volunteers collect sometimes free of cost or receive a low fee for the yearly litter clean-up from the most polluted stretches.

Figure 5. Removal of debris with plastic litter at sluice Lixhe in 2006 (courtesy staff of the sluice and Mrs Wolthuis)

4.3.4 Estimated volumes transported plastic litter

Course fraction of macro plastic litter

Most data described below was found on the internet on several actions to remove the debris from river banks and floodplain of the Meuse catchment. This data collection concerns mainly particles with a sieve size > 0.025 m and is probably not complete because of several constraints.

Table 4.1 Tentative relation between plastic pollution with items > 0.025 m along a bank line, floodplain downstream Maastricht and the maximum discharge during a flood wave

Year		Maximum discharge (m^3/s)	Average plastic pollution of the bankline (m^3/100m)	Average plastic pollution in floodplain (m^3/100m)
2010	Upstream Sambeek	1,600	0.02	Not measured
2011	Downstream Sambeek	2,200	0.003 to 0.007	0
	Upstream Sambeek	2,200	0.06 (assumed)	0.1 to 0.2

Inflow from Belgium is estimated about 100 m^3 large particles plastic litter upstream of sluice Borgharen.

The estimation of transported volumes plastic litter during a flood with a maximum discharge of 2200 m^3/s. In the stretch Maastricht – Roermond 45 km on average 100 m^3 large particles of plastic litter might have been deposited after a flood with a maximum discharge of 2,200 m^3/s in 2011. In the stretch Ravenstein – Waalwijk on average 2 to 5 m^3 large items plastic litter were collected after a flood with a maximum discharge 2.200 m^3/s. And estimated 15 % of waste material was collected and removed from the river stretch, means that 70 m^3 plastic material had been deposited in the floodplain and on the banks. This indicates that the amount of plastic litter transport reduces in downstream direction along the River Meusefrom 100 to 20 to 50 m^3 at Sambeek and a further reduction in downstream direction is possible. This is confirmed by Van Paassen (2010) who mentions that downstream of sluice Sambeek the amount of floating debris is small.

Small fraction of macro particles plastic litter

Preliminary measurements by G. Tweehuijsen (Tweehuijsen, 2013) and his team in the river Meuse near Maastricht in October 2012 indicate:

- The transport of plastic litter in the main channel can be divided in about 80 % floating plastic litter and about 20 % plastic litter in suspension and
- Plastic litter consists about 20 % of particles with a sieve diameter > 0.025 m and 80 % of particles with a sieve diameter between 0.0003 and 0.025 m

The volume of the fraction with fine particles is about four times larger than the volume of the fraction with coarse particles. These preliminary results are used in the following mass balance.

Preliminary mass balance

A preliminary estimate of a mass balance of plastic litter in the stretch Maastricht – Sambeek, 132 km distance after a flood with a maximum discharge of 2,200 m^3/s and based on a incomplete data set:

Table 1 Preliminary mass balance of floating plastic debris in the stretch Maastricht – Sambeek in a period with average floods (numbers indicate the magnitude)

Inflow	Fraction	Volume (m^3/year)	Outflow	Fraction	Volume (m^3 /year)
Upstream Maastricht	Course	100	Collection in floodplain and natural degradation	Course	140
	Fine	800		Fine	200
From other sources as recreation/agriculture/ industries/dumping	Course	100	Collection by volunteers	Course	20
	Fine	800		Fine	0
	Course		Downstream outflow	Course	40
	Fine			Fine	1400
Total	Course	200		Course	200
	Fine	1600		Fine	1600

Table 2 Preliminary mass balance of floating plastic debris stretch Sambeek - Biesbosch in a period with average floods (numbers indicate the magnitude)

Inflow	Fraction	Volume (m^3 /year)	Outflow	Fraction	Volume (m^3 including air/year)
Upstream Sambeek	Course	40	Collection in floodplain and natural degradation	Course	70
	Fine	1400		Fine	100
From other sources as recreation/agriculture/ industries/dumping	Course	50	Downstream outflow	Course	20
	Fine	100		Fine	1400
Total	Course	90		Course	90
	Fine	1500		Fine	1500

The mass balance is presented of the Dutch part of the River Meuse(concentrated on mainly floating plastic litter and an estimate of plastic particles in suspension but not including high density plastics and plastics sunk by fouling after a flood) with a maximum discharge of 2,200 m^3/s. The assumption inflow = outflow means that the storage of plastic litter in the considered stretch did not change in the period before and after the flood.

Preliminary conclusions based on tendencies derived from scarce data:

- Data on plastic litter in the River Meuseis hard to find. From photographs it is estimated that 10 to 20 % of floating debris is plastic material part of the course fraction.
- Data on amounts of floating debris is not available in a systematic way and it is fragmented.
- The volume of the course fraction of floating macro particles plastic litter reduces strongly from the border with Belgium to the Dutch Biesbosch, during a flood with a maximum discharge of 2,200 m^3/s from 100 m^3 to a magnitude of 10 m^3 plastic litter.

- The volume of the fine fraction of floating macro particles plastic litter does probably not change from upstream Maastricht to the harbour of Rotterdam, about 1400 m^3/year in a period with average floods. After an extreme flood five times more plastic litter can be transported to the North Sea, according to extrapolated results from the field measurements.

These preliminary conclusions mean that the contribution to the North Sea is relatively small, however the contribution by the harbours of Europoort - Rotterdam - Dordrecht is not considered in this report. And it is mentioned that these conclusions are based on tendencies derived from the limited and unbalanced data.

Figure 3.4 Two examples of the course fraction of plastic litter in the Meuse floodplain (left near sluice Linne, 16 February 1995 and right Lateraalkanaal nearj Linne-Buggenum after extreme flood in 1995 (beeldbank Rijkswaterstaat)

Blue = river stretch with relatively high transportation of course fraction of floating plastic litter

Red = urban centres

Figure 35 Map of Meuse cathment with the stretch with highest volumes floating debris

4.3.5 Special measures and the negative effects of floating debris

Near the villages Borgharen and Itteren large amount of debris was deposited during the flood in 2011. Questions were raised in the town council about when and by whom this debris will be cleaned up (Maastricht Aktueel, 9 February 2011). This debris irritates the local population apparently. This is also illustrated by a local artist who illuminated trees full of plastic items in the River Meuseduring a special night.

Plastic litter form markers in trees of the maximum flood level, see example in figure 4.6.

Figure 3.6 Example of tree with plastic litter after flood in 2011 in the River Meusenear Maastricht. (message in local newspaper in Maastricht)

The floating lines upstream of the barrier near Borgharen got damaged by floating debris in the past. After an incident these floating lines were replaced by stronger lines.

4.4 River Scheldt

4.4.1 Introduction

Geography

The Scheldt basin covers an area of about 22,000 km^2 in France, Belgium and the Netherlands. The main channel of the River Scheldthas a length of 350 km, of which 140 km canal sections and with 6 sluices. The average population density is 350 inhabitants per km^2 (Wikipedia) The river section between its source and Ghent is called ‘the Upper Scheldt’, between Ghent and Antwerp the ‘Maritime Scheldt’, and beyond Antwerp we’re talking about ‘Western Scheldt’. Along with the Western Scheldt, the Maritime Scheldt makes up the Scheldt estuary, which is about 160 km long. Near Ghent, the river is some 65 metres wide, and near Antwerp this is 450 metres. It widens subsequently to some 5 kilometres near the mouth at Flushing.

The Scheldt and a number of its tributaries (Durme, Rupel, Grote and Kleine Nete, Dijle, Zenne and Dender) are subject to the tidal movement. The tidal waters coming from the river mouth invade the estuary. This explains why near Flushing, over 1 billion m^3 of water flow in and out the river twice a day, whereas the yearly river drainage amounts roughly speaking to 4 billion m^3 (International Scheldt Commission).

Figure 3.9 Map of the Scheldt basin

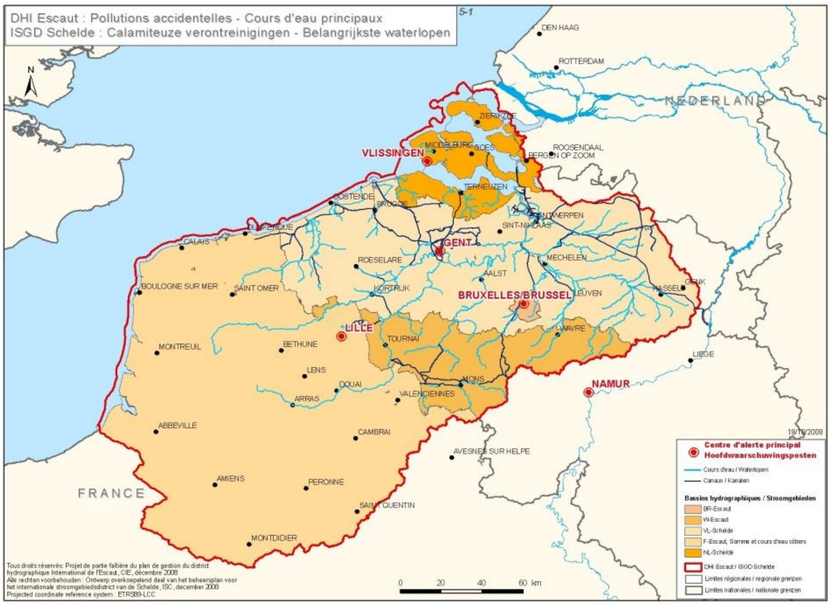


Figure 3.10 Detailed maps of the Scheldt basin with its tributaries.

The objective of International Scheldt Commission (ISC) is a cooperation between the riparian states and regions of the Scheldt River, to achieve a sustainable and integrated water management of International River ScheldtBasin District. The present tasks of this Commission do not include efforts to reduce plastic waste in the river system, but this may change in future.

The costs of the collection of domestic waste from ships are covered by the fees ships have to pay for mooring in a harbour. In the past, skippers had to pay for the disposal of domestic waste separately (Maes et al, 2001). The impression is that more waste was collected after changing the payment system.

4.4.2 Data collection

Clean-up and collection

The organization Waterwegen en Zeekanaal NV manages about 1000 km of waterways in a major part of Vlaanderen, see map in figure 3.1. The collection and removal of floating debris cost 5,32 million euro in 2010 en 4,53 million in 2011 (Gazet van Antwerpen, 10 June 2012). This means an average cost of euro 5,000 per kilometre waterway per year or around euro 500 per km^2 per year. The collection and removal of litter and debris along waterways with tidal motion are much more expensive than the collection and removal of debris along canals. In 2008, 5 June at the occasion of the World Environment Day, about 100 volunteers from different organisations collected litter in a 46 Ha tidal flat Galgeschoor near Lillo along the bank of the River Scheldtover a length of about 2 km (Natuurpunt Antwerpen Noord). Along the 320 hectare of intertidal flats called Galgeschoor and Groot Buitenschoor a regular clean-ups are organized by Natuurpunt Antwerpen Noord (Gazet van Antwerpen, 9 March 2012, Natuurpunt Noord). About 50 volunteers collected a half full container of litter in Galgeschoor in September 2012 (Gazet van Antwerpen, 17 September 2012). The neighbouring chemical plant from Solvis company supports clean-ups financially and with the participation of their staff (Gazet van Antwerpen, 12 October 2012). This initiative that companies support clean-ups is an example of education at the source and could thus serve as an example for industries.

In a management plan for the Belgian tidal flats along the River Scheldtit was mentioned that the organization Dienst voor de Zeeschelde had promised to assign a clean-up of these flats to a contractor. However this action was delayed (Provinciaal Instituut voor Hygiene, 2004).

Port of Brussels

The Port of Brussels, about 1,1 million inhabitants, considered the procurement of a special vessel to collect floating debris in the Zeekanaal Brussels and the available budget is euro 50.000 (Gazet van Antwerpen, 22 April 2005). In the harbour area floating debris accumulates near sluices and locations with low flow velocities. The lateral inflow by smaller rivers and waterways carry floating debris to the Zeekanaal. In the port of Antwerp the special vessel Condor collected about 92,000 kg floating debris in the port of Antwerp during in 2008 (Annual report 2008, Port of Antwerp).

Figure 3.11 Map of the management area of Waterwegen en Zeekanaal nv

In a preparation phase of a management plan for water recreation in Vlaanderen respondents mentioned in interviews hindrance by floating litter on the Schelde specifically (Resource Analysis and CIBE, November 2003). This plan aims at reducing this hindrance by the installation of more waste-containers in harbours for water recreation.

The company Betho collects litter on the dykes along the Western Scheldt on the basis of assigned contracts (see website Betho).

It is recommended to extend the site Scheldt Monitor with data on litter and floating debris.

Port of Antwerp

The urbanised area of Antwerp has 900,000 inhabitants, the harbour basins cover a total area of 13.000 hectares and their quay walls have a total length of 156 km. Ships produce on average 3 kg domestic waste per crew member. However passengers on cruise vessels produce much more. A vessel for inland navigation produces on average 1900 kg domestic waste per year (Maes et al, about 2001). In Antwerp they estimated on the basis of an analysis of collected questionnaires that in total 2300 ton waste is produced by seagoing vessels and 2100 ton waste by inland navigation (based on a rate of 1.85 ton per inland ship per year) in 1998.

Table 4 Estimated waste in the Port of Antwerp in 1998 (Maes et al about 2001)

Category	**Domestic waste (ton/year)**
Sea-going vessels	2300
Inland navigation	2100
Illegal dumping	1000
Packaging waste	500
Waste composed of different materials	600
Domestic waste	350
total	6850

Handling of this waste causes losses of an estimated 0.1 to 0.2 % corresponding with 7 to 14 ton/year (Maes et al, 2001). A part of this ends up as floating debris in the harbour, assume 50 % and 30 % is plastic material 1 to 2 ton corresponds to a volume 1 to 2 m^3 without air and assuming 66 % air in a volume of plastic litter it corresponds to 3 to 6 m^3 plastic litter including air.

This contribution is still small compared to the collected floating debris of about 100 ton /year by the Condor. The main part of floating debris consists of vegetation; assuming a remaining part of 35 ton of solid waste. And only a part of this is plastic waste. Assume the Condor has an efficiency of 66 % meaning that 33% or 33 ton is not collected by the Condor. Again 33 % is solid waste and that fraction consists for 33 % of plastic material: 3.6 ton or 11 m^3 volume plastic litter including air. According to the mentioned preliminary estimates 25 to 50 % might be losses by cargo handling.

Other sources of floating debris in the harbour are for example discharges from the River Scheldtand Zeekanaal, untreated discharge from sewers and litter blown by wind into the harbour.

The organisation of the collection of waste from ships plays an important role in the goal to reduce litter and floating waste in the port. In Antwerp a series of containers (35) with a volume of about 1.1 m^3 along the quays and near the sluices are used for disposal of litter. Skippers prefer containers near sluices and in harbours. In these containers 350 ton domestic waste from different sources including vessels was collected in 1998. With an estimated loss of 0.1 % a volume of 1 m^3 plastic litter ends up in the docks of the harbour, about 10 % of the estimated volume of 11 m^3 in total.

4.4.3 Overview

The Scheldt Rive has no wide floodplains only some controlled floodplain areas upstream of Antwerp. Downstream of Antwerp the width of the river increases and important tidal flats are present.

Macro plastics:
In the River Scheldtprobably the main sources of plastic litter transported by the river are debris and litter from Brussels transported via Zeekanaal, the contribution by the tributaries Rupel and others and the harbour of Antwerp: the estimated volumes for the course fraction of macro plastics: 4 + 4 + 11 = 19 ~20 m^3/ year with average floods and tides. The fine fraction might be transported in much larger volumes similarly to the River Meuse

The contribution by agricultural activities and the discharges by sewerage treatment plants are not known.

Downstream of Antwerp volunteers collect litter and debris regularly from tidal flats, estimated volume of 1 m^3 plastic litter. In the Dutch part of the Westerschelde no data was found on actions by volunteers to collect litter.

A preliminary estimation of the total contribution of the River Scheldtto the North Sea to the plastic waste is a volume of about 20 m^3/year course fraction of macro plastic litter in a period with average floods and tides. The fine fraction might be transported in much larger volumes similarly to the Meuse River.

Red = stretch with relatively high concentrations of floating macro plastics,
Orange = stretch with possibly relatively lower concentrations of macro plastics.
Blue line = Scheldt River
Figure 4 River Scheldtcatchment with the stretches where the most severe plastic pollution occurs

Table3.1.. Structure of a mass balance model

Source of litter	Transportation and processes		Change in storage of plastic litter
Supply of litter from outside river stretch	Floating	Processes	Outflow
Upstream supply	Along flowlines		Floating
Effluent sewerage treatment plant	Effect by wind		Bottom transport
Litter blown by wind into the area	From floating to bottom transport by fouling	Abrasion	Accumulation of litter
Drainage water from roads and urban areas	Suspended		Near hydraulic structures
Waste from upstream industries	Turbulence intensity		Against outer slope of dykes
Inland shipping			In bushes and trees
		UV light disintegrates plastic from solid to paraffine and finally into oil	In alluvial riverbed
	Bottom transport		
	Shear stresses		Collection of litter
			Volunteers
			Contractors
			Ingested by animals
			Blown away by wind

Microplastics
The numerous sewage treatment plants are expected to discharge microplastics in to the Scheldt River. This river basin is densely populated. However, at present no data are available about microplastics in the Scheldt River.

4.5 Estimation contribution of plastic litter from Dutch rivers to the North Sea

Meuse River
The River Meuseupstream of the nature reserve Biesbosch carries the course frction of floating macro plastic litter with an estimated volume of about 10 to 100 m^3 in periods with average floods. The transport of the fine fraction is about 100 to 1000 m^3 in similar periods. After an extreme flood this volume will be higher. Downstream of Biesbosch the harbours of Rotterdam will discharge an additional unknown volume floating macro plastic litter to the North Sea.
In addition the River Meusedischarges an unknown volume of suspended macro plastic litter with foil like shapes to the North Sea. In the silt transport an unknown concentration of microplastics are transported to the North Sea.

Rhine River
In this study insufficient data were collected to estimate volumes of floating macro plastic litter in the River Rhinedischarging in the North Sea.

Scheldt River
The River Scheldtcarries the course fraction of floating macro plastic litter with an estimated volume of about 10 to 100 m^3 in periods with average floods and tides.
After an extreme flood and extreme tides this volume will be higher. Downstream of Antwerp the harbours of Flushing will discharge an additional unknown volume floating macro plastic litter to the North Sea.
In addition the River Scheldtdischarges an unknown volume of suspended macro plastic litter with foil like shapes to the North Sea. The fine fraction might be transported in much larger volumes similarly to the Meuse River. In the silt transport an unknown concentration of microplastics is transported to the North Sea.

Extrapolation
The estimated volumes of plastic litter discharged via these rivers in the North Sea might have a magnitude of 10,000 m^3/year by based on extrapolation of very few data. This discharge might be compared to the estimated volume of litter in the North Sea.

North Sea
The total volume of macro plastic litter can be estimated roughly assuming a plastic particle has a volume of 0.5 litres on average and the North Sea covers an area of 750,000 km^2
1.5 items/hectare* 75 million hectare * 0,001 m^3 = 56,000 m^3 plastic litter in the North Sea
This indicates that a total volume of plastic litter in the North Sea of about 60,000 m^3.

The catchment areas of the rivers Meuse Rhine Scheldt are in total about 220,.000 + 22,000 = 242,000 km^2 form a significant part of all catchment areas discharging in the North Sea, 840,000 km^2, it is about 30 %. A first estimate is that these rivers contribute also 30 % of plastic litter in the North Sea minus the contribution by navigation and other sources, 30,000 m^3. The all rivers discharging in the North Sea contribute 30,000 m^3 plastic litter. The Meuse, Rhine and Scheldt contribute 0.30 * 30.000 = 9,000 m^3. If the average life time of a plastic particle is assumed at 2 years in the Norht Sea, than the inflow of 4.500 m^3/year by these three rivers fits reasonably well with the estimated discharges of plastic particles in these three rivers.

The total picture seems to be consistent concerning the transport of plastic litter in the three rivers and the presence of plastic litter in the North Sea. Although this picture confirms more or less the expectations of experts, it is mentioned that all figures are indicative. Because of the lack of data the presented estimations and extrapolations are likely underestimations of the true volumes of plastic litter.

4.6 Data gaps for litter in Dutch rivers

The limited data collection has resulted in some interesting data, but it does not cover all aspects of the plastic litter in the Rhine, Meuse and Scheldt Rivers. The following type of data is missing:

Data per river basin

- Data on litter and other debris in the upstream stretch of the rivers,
- The inundation areas or flood plains of the rivers in historical floods,
- The sources of plastic waste are not determined for example waste originating from agricultural activities, urban centres and industrial activities in a river basin. Data on illegal dumping of garbage in a flood plain are scarce.

Macro plastics

Contractors remove debris in the flood plain after a flood and information about the following aspects is missing::

- the area cleaned is not known,
- the effectiveness of a removal action with respect to the plastic litter and
- the fraction plastic litter in the total volume of removed debris,

Municipalities remove floating debris from harbours. The volume and the composition of removed debris in harbours is not known.

The volumes and compositions of debris and litter collected by volunteers often on a yearly basis is missing. OSPAR lists distinguish different litter items, but information about the volumes of these items is missing. Filling in these lists is a step forward. Most plastic litter is floating and is transported by a combination of flow and wind. Systematic data on suspended plastic items with a foil like shape is almost completely missing and also data about plastic litter on the river bed is not available.

Microplastics

The volumes, types and sources of microplastics form a big knowledge gap in the considered river basins. Only little information is available, results of the few studies available are reported in appendix A.7. It is well possible that microplastics, especially primary microplastics from consumer products, that are possibly only partly removed in STP effluents may end up in riverine systems (Leslie et al., 2012). On the other hand, microplastics may end up in sewage sludge, and through run-off may end up in the rivers. This could be particular the case for the river Rhine since sewage sludge is commonly still used in Germany on agricultural land as a fertilizer or dust suppressant.

Quantative data on the discharges by sewage treatment plants in a river basin and the concentration of microplastics in that discharge will be collected in the near future.

Database

It is recommended to collect the data and to store these data in a database. Databases in the countries bordering the North Sea should have all a similar set-up. In a separate public database volunteers should be able to enter data on the plastic litter they had collected.

4.6.1 Litter and debris in rivers abroad

A provisional comparison is made between litter aspects in the main rivers in the Netherlands, Singapore and Korea, see Table 2.3. Background information is found on litter in these countries in appendix C.

Table 2.3 Comparison of the riverine litter in the Netherlands, Singapore and Korea

	Fine (€)	**Enforcement**	**Organisation**	**Amount of litter in the riverine system (m^3)**	**Money spent to clean up and prevent litter (€)**
Netherlands	60-120	+/-	Nederland Schoon, Milieu Centraal	1000	250 million
Singapore	190	++	National Environment Agency, Waterways Watch	unknown	19 million
Korea	unknown	unknown	unknown	32,000-175,000 (on 16 rivers combined)	unknown

The plastic pollution and the amount of floating debris in Korean, Indonesian rivers need even more attention than in the Netherlands. The examples of Korea and Singapore are mentioned here because both countries are highly developed societies and are thus comparable with the Netherlands. Furthermore, Singapore has made progress in keeping their rivers clean and in Korea large interventions to collect and to remove floating debris are common. In Indonesia the problem of litter in rivers is well known, but the way to improve the situation to standards accepted in Western Europe is probably long. The Netherlands can profit for the development of their policies from the experiences in other countries.

5 Modelling litter transport in rivers

5.1 General introduction

Modeling of the transport of litter in a river system is a tool to understand the physical process and it most important parameters. A model needs calibration on observed processes. A model can be used for the following purposes:

- To predict the transport of plastic litter in extreme events, for example rainfall and floods,
- To determine hotspots of plastic litter in river up- to downstream
- To predict the effect if a source, for example an industry, reduces its emissions
- To predict the impact of new legislation and regulations, for example resulting in less illegal dumping in a flood plain
- To predict the effect of changes in the operation of hydraulic structures in a river or other change in the flood plain (measures for a Room for the River program)

A model is always a schematization of the reality. Therefore the results of a simulation with a model need careful interpretation. Models differ in their accuracy the reality is schematized and the length of the schematized stretch of a river. The simplest model is a model that is based on conservation of mass of litter. The basic characteristic of such model of a river stretch is:

Input of mass of litter = change of mass of litter in the stretch + outflow of mass of litter

A more complicated model is a transport model that connects the transport of plastic litter to the time dependent hydrodynamic flow phenomena in a river. At present, powerful 1dimensional and 2 dimensional well calibrated hydrodynamic models are available for the most important West European rivers. In principle these models can be extended with a plastic transport module.

5.2 Conceptual models

A conceptual model offers a framework to understand the complex phenomena related to the transport of litter in a river system. A conceptual model aims at a general validity that allows application of the model in various river systems. A first attempt to set up a conceptual river litter transportation model was made by G. Tweehuysen, see figure 4.1 also research proposal (Tweehuysen, 2012).

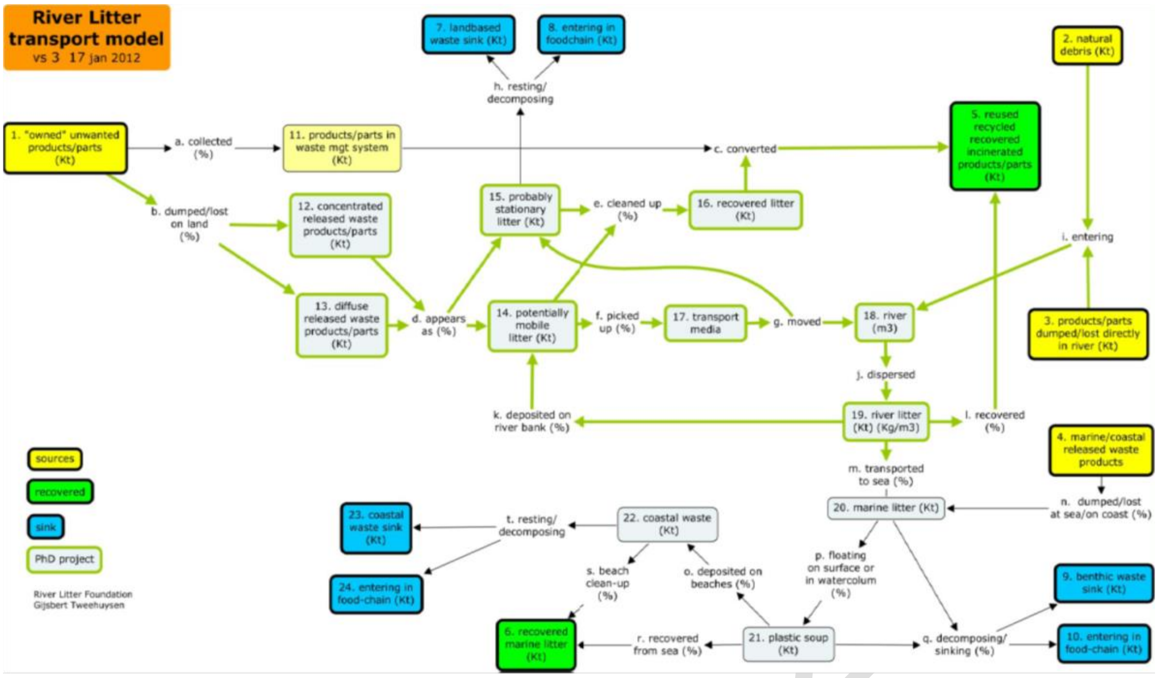


Figure 4.1 Conceptual model of transportation of plastic litter in the River Meuseaccording to G. Tweehuysen

The complex model of Tweehuysen has been simplified to a simple mass balance model for a stretch of a river.

Supply of litter from outside river stretch

- Upstream supply transported by a river
- Effluent sewerage treatment plant
- Litter blown by wind into the area
- Drainage water from roads and urban areas
- Waste from upstream industries
- Inland shipping

Supply of litter from activities in the considered stretch

- Agricultural activities in the floodplain
- Illegal dumping of waste materials in the floodplain
- Recreation in the floodplain including camping's and ships
- Local industries in the floodplain
- Inland shipping

Outflow of litter from the considered stretch:

- Outflow transported by the river

The structure of a simple mass balance model is sketched in table 4.1. This simple model is a first model and it might be developed to a more complex model in the future. This model was used to estimate the transport of plastic litter to the North Sea via the River Meuse(appendix D) and the River Scheldt(chapter 3).

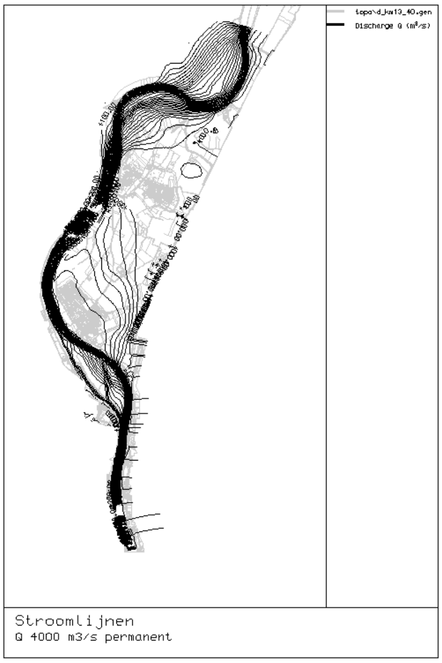
Table 4.1. Structure of a mass balance model

Source of litter	Transportation and processes		Change in soirage of plastic litter
Supply of litter from outside river stretch Upstream supply Effluent sewerage treatment plant Litter blown by wind into the area Drainage water from roads and urban areas Waste from upstream industries Inland shipping	Floating Along flowlines Effect by wind From floating to bottom transport by fouling Suspended Turbulence intensity Bottom transport Shear stresses	Processes Abrasion Uv light disintegrates plastic from solid to paraffine and finally into oil	Outflow Floating Bottom transport Accumulation of litter Near hydraulic structures Against outer slope of dykes In bushes and trees In alluvial riverbed Collection of litter Volunteers Contractors Ingested by animals Blown away by wind

5.3 Two dimensional models

Based on this conceptual mass balance model detailed information on the locations where litter will accumulate can be obtained from a two dimensional Delft3d model of for example a stretch of the Meuse River. A Delft3d model uses data on the elevation and the roughness of the floodplain. The hydraulic roughness Is determined by the detailed classes of ecotopes. As an example a stretch is of a model of the River Meusejust upstream of Maastricht is presented in figure 4.2. A plastic particle follows a computed track determined by the wind force and the flow lines. The model calculates where and when a plastic particle will stick to the bank where the roughness is high and the water depth is small.
The simulation of a historical flood and the assumed release of plastic litter at the upstream boundary will provide improved knowledge about the sources of plastic litter, the transportation distance of plastic litter during a flood and the bank lines where the highest concentrations of plastic litter can be found. The computational results can be analysed to set up a tool for a monitoring program. Field experiences and a tool based on Delft3d computations are combined to design a flexible monitoring program of plastic litter in the Meuse River.

As a first step it might be considered to execute pilot computations of the effects to show the accumulation of debris on the banks of the River Meuseduring a selected historical flood and to compare the results with the places where observations show accumulation of litter. This can be used to design measures to concentrate the accumulation of litter in a flood plain. This concentration will reduce the cost for removal of litter from the flood plain. These measures can be low cost, such as modest changes in the flood plain vegetation.



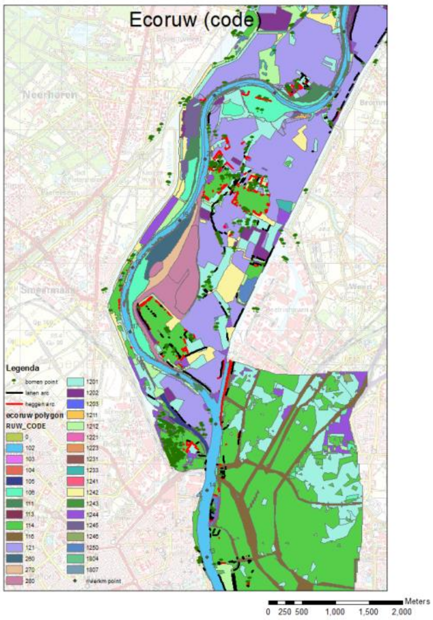


Figure 6.2

Figure 5.2 Example of the depth averaged flow lines in the River Meusedownstream of Maastricht at a permanent discharge of 4,000 m3/s (left) and hydraulic roughness of the flood plain represented by ecotopen.

6 Monitoring methods

6.1 Introduction

The monitoring of plastic litter in the marine environment is more developed than the monitoring of plastic litter in river basins. Therefore it is strived after standard monitoring protocols for litter in rivers at the same set up as the monitoring methods applied in a marine environment. Monitoring methods for the marine environment are summarized in Section 6.1. The instruments used for monitoring are described in Section 6.2 and the monitoring methods for rivers in Section 6.3

6.2 Marine environment

Monitoring of debris in the North Sea is regularly conducted on beaches as well as by analysing the stomach content of northern fulmars (OSPAR EcoQO). Additionally, there are beach clean-ups, organized by NGOs according to OSPAR protocols. In rivers there are no standard monitoring programs yet, even though there are many clean-up programs depending largely on volunteers. For microplastics, , specific monitoring indicators are proposed but need further development. This includes the use of a high speed manta trawl to measure the amount of floating microplastics of the surface layerRecommendations for protocols and requirements are provided by EU Technical Subgroup on Marine Litter (REF). Up to now, only the monitoring of fulmars and the beach clean-ups are executed according to a standardized method. The other monitoring methods have not been standardized yet, thereby making it difficult to compare results.
Furthermore, there are different ways of sampling litter in the marine environment. A review (Sprengler & Costa, 2008) showed that there are at least 6 different methods: bottom trawl net, sonar, submersible, snorkeling, scuba diving and manta tow.

6.2.1 Northern fulmars

Northern fulmars (*Fulmaris glacialis*) are birds that spend a large part of their lives at sea. This species is therefore used as an indicator of floating debris by OSPAR. Between 2003 and 2007 95% of the 1295 fulmars sampled in the North Sea had plastic in their stomach and the critical level set by OSPAR of 0.1 g was exceeded at more than half of the birds (Van Franeker, 2011). Since the 1980s, fulmars have shown a decrease of industrial, but increase of user plastic. Shipping and fisheries are thought to be the main sources of this shift.

6.2.2 Beaches

Beach monitoring provides some information on the amount of litter washed ashore from sea. There is also input from active littering by tourists on the beach itself, as well as possible plastics being moved by wind from land. Stichting de Noordzee has set up the Coastwatch program in the Netherlands, and organizes beach clean-ups regularly. The beaches chosen are not touristic beaches, this to get the best indication of the amount of litter coming from sea. The protocol for these clean-ups originates from OSPAR and the program has a strong educational component, involving school children.

The OSPAR protocol for beach litter monitoring (OSPAR, 2007) is described as follows:

- Select which marine litter items to include in a survey protocol/survey protocols, i.e., which items and number of items to count and register in surveys.

- Establish standard rules regarding the removal or marking of all marine litter items after counting and registration.
- Establish set criteria for the selection of beaches for regular monitoring.
- Devise a universal form for the collection of data from each beach.
- Identify and select the beaches to be monitored, allocating each beach a reference number, and completing the documentation.
- Establish a standard length of survey section(s) on each beach.
- Mark this/these section(s), using permanent reference points.
- Establish annual survey periods.
- Select a data host. Set up a common, internet-based database.
- Carry out the surveys, using the agreed protocol in accordance with other agreed procedures.
- Establish a system to allow surveyors to input their gathered beach data to the database (transfer registrations and observations from survey protocols to the database) after each survey.

According to the results of Coastwatch, 20,000 ton of debris ends up in the North Sea on an annual basis. On beaches, around 400 litter items per 100 m beach are found (presentation Lex Oosterbaan, litterl stakeholders meeting). Approximately half of the debris found on beaches consists of plastics (49%, see figure 6.1 followed by ropes and nets (13%) and wood (12%). It is thought that approximately one third of the litter on beaches stems from land based sources .

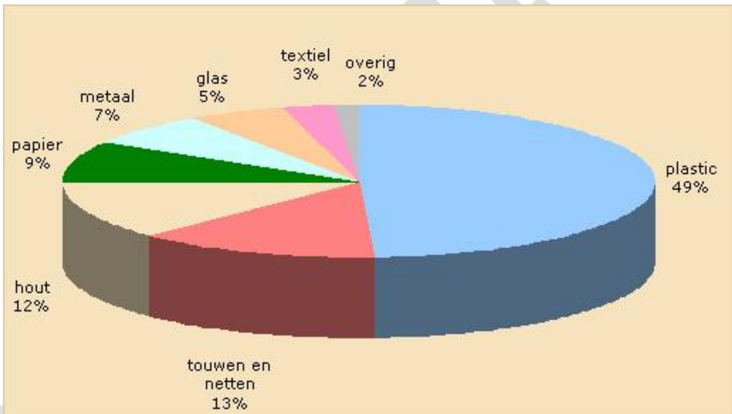


Figure 6.1 Materials of the debris found on beaches

The proportion of plastics is 75% on reference beaches in the Southern North Sea during the Pilot Project on Monitoring Marine Beach Litter (2007). This value is higher than that in the Coastwatch project.

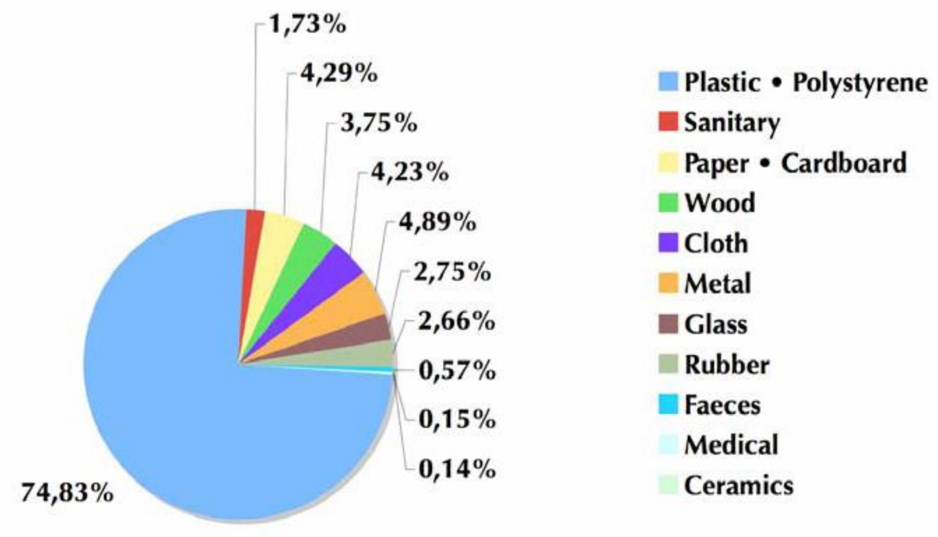


Figure 6.2 Composition of littr (which litter???)

6.3 Sensors

There are advantages in using sensors over visual methods such as objectivity and reproducibility of results. Veenstra and Chopard (2012) therefore propose to use sensors in monitoring of plastic debris. They make a distinction between passive and active sensors and focus mainly on airborne sensors operated from an airplane. Some of the methods they propose are able to penetrate the upper water layers, however, the one of the main issues with this method could be the underestimation of plastics, since mainly the floating plastics are taken into account. Furthermore, this method would only be suitable for large marine debris, and would not take the smaller particles into account.
Nog toevoegen Nakashima et al., 2011 over fotografie vanuit de lucht als methode voor stranden.

6.4 Rivers

In the Netherlands, the only study so far that has used a method to assess riverine litter is Van Paassen (2009). She uses the OSPAR method used for assessing beach litter. In the USA, several streams were measured using a different method, the Rapid Trash Assessment Method (Moore, 2005). The method is as follows:

- All trash items per 100-foot section of stream of shoreline were sampled
- Trash above and below high water line were collected
- Samplers also looked under bushes, logs, vegetation, etc.
- Items were scored based on six categories:
  - Level of trash
  - Actual number of trash items found
  - Threat to aquatic life
  - Threat to human health
  - Illegal dumping and littering
  - Accumulation of trash

In river clean-ups there is usually no monitoring involved since the main motivation is to get rid of the litter in place (see chapter 4). At best the total volume of collected waste, the length of the cleaned-up bank or the size of the cleaned-up area are mentioned in reports of a clean-up along a river bank or in a floodplain. In Western Europe a standard, preferred frequency is once per year after the season with floods.

6.4.1 Microplastics

The methods used to monitor microplastics are different from those of macro-debris since these cannot be monitored visually.

1. Water surface

The main method for assessing microplastics on the water surface is Manta trawling. This net (with a mesh sizes typically of 333 micrometer) skims the upper 50 centimetres of the sea surface. In using a Manta trawl however, the total amount of plastic in the upper water column may be underestimated by a factor of up to 27 (Bergmann & Klages, 2012). Furthermore, densities of plastics may change through fouling with marina organisms, and may therefore appear in different parts of the water column during their lifetime.

Even though Cefas (UK) and NOAA (USA) have set up protocols or guidelines for microplastics, these are not yet standardized (Leslie et al., 2011).

2. Sediment

Sediment can be sampled with a sediment grab, such as an Eckman grab, Van Veen grab or a sediment core. The collected sediments are then made into a slurry with a saturated salt solution causing low density polymers to float (Thompson et al., 2004). This solution is then sieved and analysed under a microscope. Protocols are currently developed in the Interreg MICRO project.

3. Organisms

Analysing the gut contents of birds, mammals, plankton, fish, crustaceans and bivalves provides an indication of the amounts of microplastics ending up in the food chain. Several studies have sampled microplastics in biota, mainly in lab experiments (Leslie et al., 2011). The number of publications indicating the presence of microplastics in marine organisms rapidly increases and includes a wide range of animals (seals, birds, fish, crabs, mussel, lugworms, etc) . By feeding organisms fluorescent beads, plastic particles can be tracked trough the digestive system and histological samples taken from tissues show accumulation of microplastics in the organism. Evidence that microplastics can be taken up in the tissues and body fluids of field organisms is increasing (REFs).

4. Analysis

Since the main analytical methods are based on visual inspection, there is a lack of objectivity in collecting data on microplastics. Furthermore, due to the labour intensity of the work, costs of analysis are quite high. Ligth microscopy, and cytometry are used to determine the amount and type of microplastics in a sample (Leslie et al., 2011). For determining of the polymeric composition microscopy techniques are Fourier transform infrared spectroscopy (FTIR) and Raman microscopy. . Sampling methods and sampling treatment need further development, especially for sediments and biota.

7 Legislation on and management of litter

7.1 Introduction

In this chapter an overview is given of the legal context of the marine litter issue, with a distinction between EU, international, regional, national and local level.

Table 5.1 Overview relevant legislation on management of litter and debris

Sources	
Waste Framework Directive (Directive 2008/98/EC)	Sets out essential conditions for waste management and concerns all types of waste. The Directive introduces a binding waste hierarchy, defining the order of priority for treating waste in prevention is the first and landfill the last.
Packaging and packaging waste directive (Directive 94/62/EC)	Sets a range of requirements to reduce the impact of packaging and packaging waste on the environment. This directive only focuses on packaging. Closing the loopholes in plastic packaging cycle.
Europe 2020 Strategy	Long-term action framework/ roadmap for a resource efficient Europe addressing also the issue of reduction of marine litter; calling for oa biobased economy
Raw Materials Initiative	Proposed measures to improve the recycling market functioning in order to reduce materials being wasted
Landfill Directive (Directive 99/31/EC)	Establishes technical requirements for the operation of landfills, with the goal of reducing their impact on the environment, including the pollution of surface water.
Ship-source Pollution Directive (2009/123/EC)	Translation of the MARPOL convention in EU legislation preventing the discharge of polluting substances.
Port Reception Facility Directive (Directive 2000/59/EC)	Aims to reduce waste entering the ocean from the shipping industry by the providing port receptive facilities for waste.
Urban Waste Water Treatment Directive (Directive 91/271/EEC)	Addresses prevention of pollution streams from sewage treatment plantsand stormwater discharges
Impacts	
Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC)	Aims to maintain clean and healthy oceans by 2020 through achieving Good Environmental Status (GES). This includes a descriptor on litter (descriptor 10). Providing an overarching framework for oa. the Habitats Directive, the Birds Directive and Water Framework Directive all in line with the Regional Seas Conventions Action Plans
Integrated Maritime Policy (IMP)	Aims to maximise sustainable use of the oceans and seas while enabling growth of the maritime economy and coastal Regions.
Integrated Coastal Zone Management (ICZM)	Defines the principles of sustainable management and use of coastal zones.
Water Framework	Directive that focuses on fresh water, including the coastal

Directive (WFD) (Directive 2000/60/EC)	zone. Ecologically sound surface waters should be achieved by 2015 in EU all member states in river basin districts. Contributes to the MSFD goals.
Fisheries Directive (Directive 2006/44/EC)	Directive that focuses on the quality of fresh waters needing protection or improvement in order to support fish life

7.2 International level

The EU and it's member states collaborate in amongst others the UN expert group on marine litter, GESAMP.

The Honolulu Strategy, following from the UNEP and NOAA organised convention in 2011, envisages a reduction of both land-based sources as well as sea-based sources of marine debris. No targets were formulated within the strategy, but it was emphasised that the areas of Integrated Solid Waste Management (ISWM), and Extended Producer Responsibility are clearly relevant to the scale and nature of the marine debris problem. Target setting has to be done by the implementing nations.

The RIO 20+, UN Sustainable Development Summit of June 2012 agreed on the importance of the issue of marine litter by aiming to reduce marine debris 'significantly' by 2025. Recently, Annex V of the MARPOL (International Convention for the Prevention of Pollution from Ships) was revised and now prohibits the discharge of all garbage anywhere into the sea. This includes all food, domestic and operational waste. The North Sea is designated as Special Area under the MARPOL convention due to the problems associated with the heavy maritime traffic (Website MARPOL).

Europe has four regions that are governed by Regional Sea Conventions to which the implementation of the Marine Strategy Framework Directive is closely related. The Conventions also play an important role in the implementation of the UNEP Global Program of Action for the Protection of the Marine Environment from Land-based Activities (GPA) that also addresses marine litter as one of their focus points. During a Rio20+ side event on marine litter the Global Partnership on Marine Litter was launched last June with the aim to resolve this trans-boundary problem in the knowledge that it requires a multi-stakeholder approach at all levels involving international organisations, governments, industry, nongovernmental organisations, citizens and other stakeholders.

The Marine Strategy Framework Directive (MSFD) aims to achieve Good Environmental Status (GES) by 2020 and includes the descriptor 'Marine Litter' (descriptor 10). National authorities in the Netherlands are implementing the MSFD and need to provide the European Commission with input on the amounts of macro and micro litter in the Dutch marine environment. For freshwater, one of the main policy instruments to control water quality is the Water Framework Directive (WFD) which aims to achieve good chemical and ecological status by the year 2015. The WFD however does not include litter or plastic debris in determining this good status

7.3 Regional level

The Regional Sea Convention North-East Atlantic applies for the Netherlands. The Bucharest and Barcelona Conventions have protocols to address land-based marine pollution where OSPAR and Barcelona Convention are developing a regional action plan on marine litter.

In 2013 three studies will be published under the FP7 program that will be the basis of the further development of the EU's policy framework: i) Feasibility on introducing instruments to prevent littering; ii) Study on the largest loopholes within the flow of packaging material; iii) Pilot project- plastics recycling cycle and marine environmental impact.

In addition the ‘CLEANSEA’ project, under the ‘Ocean of Tomorrow’ call has started 1 January 2013 and aims to deliver a toolbox in 2016 for EU member states to obtain GES concerning descriptor 10, marine litter within MSFD.

Much is to be expected of the publication of the EC’s policy paper ‘Green Paper on plastics’ that was planned before end 2012.

Under the Water Framework Directive member states draw up river basin management plans in which they set out their measures to improve the GES of the water in rivers, estuaries, coasts and aquifers. There are national and international integrated river basin management plans. For the Netherlands these comprise four regions – Ems, Rhine, Meuse and Scheldt rivers- that have been jointly summarised into one international catchment plan for the entire delta. International River Commissions are the communication platforms for member states to discuss, integrate and coordinate their national river basin management plans.

Further to the regional coherent effort to reduce plastic litter entering into the aquatic and marine environment, the interactions of the legal framework described above require tuning. If the overall governance framework does imply a single signalled approach, member states will be challenged to enforced the different legal frameworks coherently without further delay.

To be able to assess the aims and goals of such implementation, uniform monitoring methods will have to be developed in order to assist the member states to gain knowledge of the present status and deliver the required Good Environmental Status and report to the EC on the parameters to be set. EMODnet or other data networks, like SEIS, both presently under development may be a way to incorporate and share data. Under the Water Framework Directive member states draw up river basin management plans in which they set out they measures to improve the GES of the water in rivers, estuaries, coasts and aquifers. There are national and international integrated river basin management plans. For the Netherlands these comprise four regions – Ems, Rhine, Meuse and Scheldt Rivers- that have been jointly summarised into one international catchment plan for the entire delta. International River Commissions are the communication platforms for member states to discuss, integrate and coordinate their national river catchment plans.

7.4 National level

In The Netherlands, all the governing bodies involved in water management (execution by Rijkswaterstaat, Waterboards (both national), Provinces, Municipalities (both local) and the responsible Ministry of Infrastructure and Environment) collaborate intensively to fulfil the obligations of the WFD to the European Committee. The Secretary of State of the Ministry bears final responsibility at European level. All governing bodies collaborate at catchment level on the prevention of litter flowing downstream, however, only Rijkswaterstaat Limburg has a regulation in place in which they address the issue of litter; the river Meuse being the major –as we believe at present- contributor of plastics downstream into the North Sea, judging from the amounts of litter that remain behind on the floodplains after the annual flood peak during the winter/ early spring. Rijkswaterstaat Limburg will reimburse the costs following disposal of the litter that has been collected after the flood peak only during that peak period; during the rest of the year the costs are borne by the land owners in the/ floodplain.

With the present organisational changes within Rijkswaterstaat it is to be expected that a more integrated national approach will be implemented also in the view of the central approach, ‘one border governing’ following from the first evaluation by Rijkswaterstaat of the Water Law (Waterwet) -launched on December 22nd 2009-.

Litter though remains an issue to be addressed in close collaboration between all countries in the separate river catchments, hence international cooperation is required. On both formal and informal level there are many contact moments however, since the different organisations do not have the same responsibilities and tasks dedicated at the same level, it has proven to be harder than initially thought to coordinate this at catchment level -like other issues have proven to be similarly difficult to manage-.
Rijkswaterstaat has made an effort to create an 'Atlas' of the different organisations, management levels and people involved. It seems that cultural differences also play a major part in the structural communication lines required (personal communication 2012).
The governing bodies are inspected on their performance and transparency by the Supervisory board water management (Inspectie Waterbeheer IVW/WB) of the Ministry of Infrastructure and Environment, the issue of litter though is not incorporated in their plans since it is not in the legal (hence WFD) requirements. The IVW supports the Ministers' (system) responsibilities, nationally, internationally and legally.
The Law on Environmental Governance (Wet Milieubeheer) that is executed locally by the municipalities through their local regulation on Waste Management (Afvalstoffen regelgeving) does not clearly describe (street- or other) litter, although there is a NEN standard that does hand us a workable definition for litter:
"Waste found on streets, squares, parks, gardens, forests, along roadsides and riverbanks, in canals and ditches and recreational areas; a large collection of objects or substances in the waste stage."
In general Water related laws will speak of emissions, either point or diffuse releases, the incorporation of (aquatic- or street-) litter in the definition of the 'emissions' would greatly improve the possibilities for water managers to adequately register, monitor and assess the risks related.

In the Netherlands several large organizations are active in the field of nature conservation of tidal flats and floodplains in rivers. The main organizations are: Staatsbosbeheer, Natuurmonumenten en De 12landschappen

The 12landschappen is a foundation of the Unie van Landschappen to enhance cooperation between the 12 separated Landschappen and to strengthen their influence on the formulation of national policies regarding nature conservation and to simulate coordinated fund raising. In every province a Landschap is active.

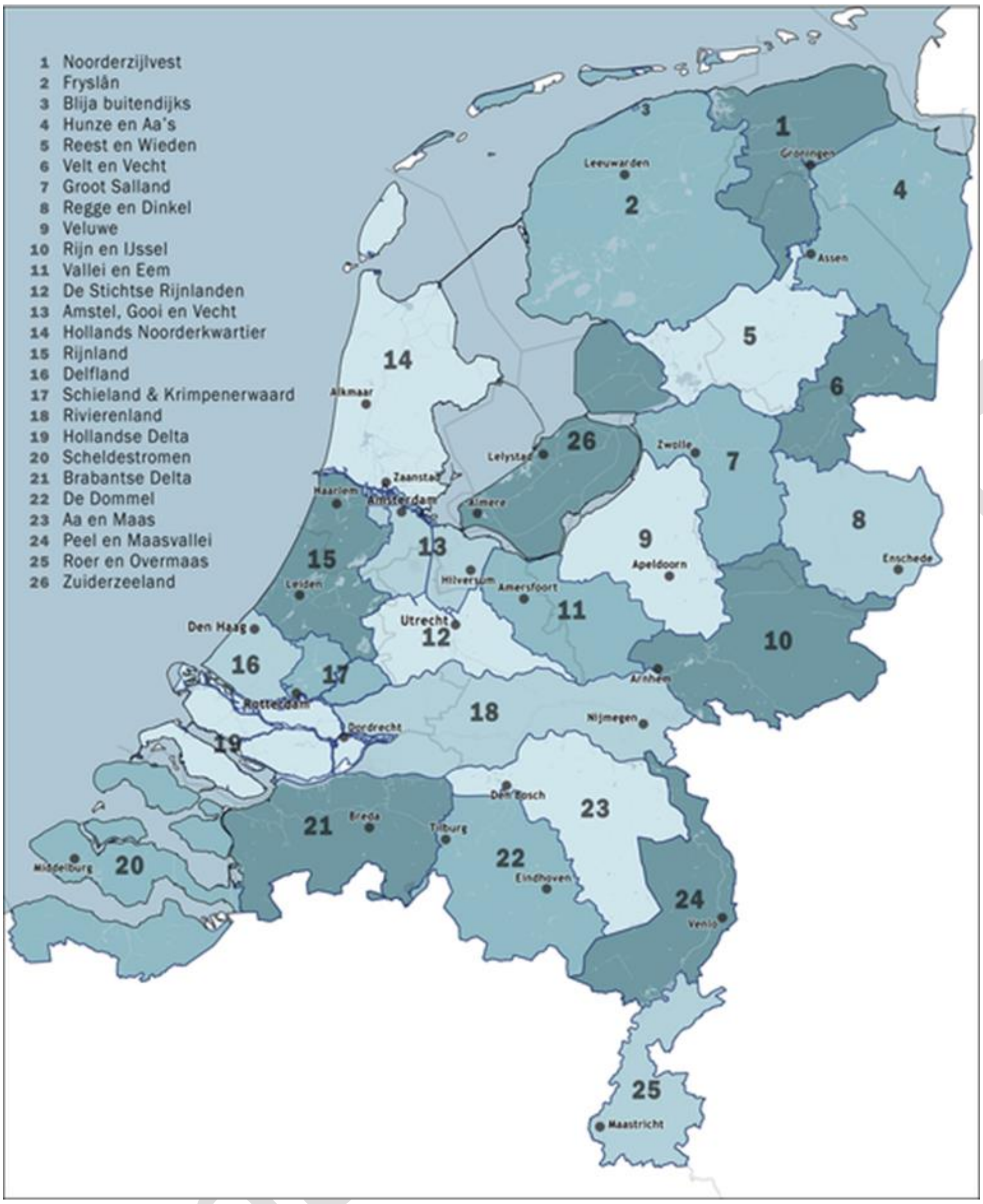


Figure B.2 The management areas of 26 water boards in the Netherlands

7.5 Local municipal level

The responsibility of the removal of the litter/ debris left behind is a municipal task outlined in the Law on Environmental Governance, described above. The financing of this task has changed over the recent years; presently it is partly financed by the Wastemanagement fees (afvalstoffenheffing) civilians pay and by the industry through their extended producer responsibility obligations that were met in the creation of the Waste fund (Afvalfonds). Assessing the funding-sources is beyond the scope of this study so it will not be addressed further.

The Union of Dutch Municipalities, VNG is working in close collaboration with the executing bodies NL Agency and the NVRD (Royal Dutch Association for Wastemanagement) on their program 'Clean municipality' (Gemeente Schoon). The NVRD is the largest national waste management association of the Netherlands. The NVRD unites municipalities responsible for waste management and management of the public space and the municipal waste

management companies in the Netherlands. The program ‘Clean municipality’ for, through and by municipalities addresses litter in general and has recently acknowledged the importance of preventing upstream pollution to be transported downstream.
One of their pilot projects is ‘Clean Water Limburg’ (Schoon Water Limburg), where the litter that is left behind on the flood plain of the Meuse river, after the winter flow peak is removed in close collaboration between municipalities, Rijkswaterstaat and the Province of Limburg. In The Netherlands, all the governing bodies involved in watermanagement (Rijkswaterstaat, Waterboards, Provinces, Municipalities and the Ministry of Infrastructure and Environment) collaborate intensively to fulfil the obligations of the WFD to the European Committee. The Secretary of State of the Ministry bears final responsibility at European level.

8 Conclusions and recommendations

8.1 Conclusions

The authorities in the Netherlands are implementing the Marine Strategy Framework Directive to ensure Good Environmental Status by 2020. This benchmark includes that the conditions for marine litter in the North Sea has to be fulfilled. A main part of the marine litter is thought to be through input from land based sources and discharges from rivers. In this study an inventory is made of available litter data in the three major Dutch rivers, the rivers Rhine, Meuse and Scheldt. A quick scan yielded only limited litter data for these rivers basins. Using the scarce data, the transport is described of plastic litter via the three main rivers into the North Sea. In addition recommendations for monitoring riverine systems are formulated. The available data is incomplete; therefore also an inventory of missing data has been included in this report.

Conclusions

General description
Floating plastic litter receives most attention because floating plastic litter is visible and thought to be a main part of all plastic litter in a river. .Floating plastic litter is a fraction of the volume of floating debris mainly consisting of vegetation (branches, roots, leafs) in a river. This fraction is often small. The highest concentration of plastic litter is observed during floods as flood plains are inundated. After inundation dispersed plastic litter starts to float in a flood plain. The pathway of floating plastic litter is determined by flow lines at the water surface and the force exerted by wind on the litter. A pathway ends at a bank, in vegetation still topping above the water level or at hydraulic structures.

Mode of transport
The transport of plastic litter can be schematized in several ways:
A classification by size (a diameter.> or < 5 mm) or by transport mode: bed load, suspended load and floating. A small fraction of the transport of litter in a river is bed load of plastic litter with a specific weight more than the specific weight of water. The most visible fraction is floating plastic litter during floods and the transport of plastic litter with a foil like shape is the so called suspended load.

Sources of litter
The data on the source of litter in rivers is often missing and the source is often unknown. Some typical sources can be found in urban areas in a river basin while other sources are predominantly in floodplain areas. These sources are expected to contribute to plastic litter transport in the Rhine, Meuse and Scheldt Rivers:

Urban areas in the catchment:

- Effluent from sewage treatment plants,
- Litter blown by wind,
- Direct rainfall run-off from parks, cities and roads to a river,
- Waste from industries in urban areas
- Loss of cargo in harbours during handling (mainly inland navigation)

- Waste of households on ships

Floodplain areas

- Inflow of litter from tributaries
- Run-off rain water from agricultural field
- Discarded litter from recreation in or near the floodplain in the vicinity of population centre
- Illegal dumping of litter in the floodplain
- Industrial effluents and spillage in the floodplain
- Litter blown by wind from outside a floodplain

Quantification of transported plastic litter
A simple model is a mass balance model that is applied on a stretch of a river.

<u>River Meuse</u>
The data is by far not complete but the inflow of the course fraction of macro plastic litter from Belgium has a magnitude of 100 m^3/year and the outflow of floating plastic litter near Dordrecht has the same magnitude. The travel time of this course fraction can be relatively long, compared to the average travel time of fine fraction and the microplastics which is expected to be relatively short. The inflow of the fine fraction of the macro plastic litter has a magnitude of 1000 m^3/year in a period with averaged floods. During extreme floods the transport of plastic litter can be much larger.
The maximum concentrations of the course fraction of floating macro plastic litter are expected in the stretch Namur – Sambeek and less variations in the concentration are expected in the fine fraction of plastic litter. No significant data has been found on the contribution by the harbour area from Dordrecht/Moerdijk to Europoort near Rotterdam.

<u>River Scheldt</u>
The data is by far not complete but the contribution of the River Scheldtmight have a magnitude of 10 m^3/year course fraction of floating macro plastic litter.
The maximum concentrations of this curse 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. The transport of the fine fraction of macro plastic litter might be much larger than the transport of the course fraction, similar as in the river Meuse. The transport of micro plastic litter has to be added to estimate the total transport of plastic litter in the river Scheldt. The contribution by the harbours in Terneuzen and Flushing have to be added too, but no data are available to estimate this contribution. During extreme floods the transport of plastic litter can be much larger than in periods with average floods and tides.

<u>River Rhine</u>
The data collection is incomplete but it is demonstrated that plastic litter can be found in the stretch from Basel to Rotterdam. A quantification of transport rates is impossible on the basis of the available data.

The estimated volumes of plastic litter discharged via these rivers in the North Sea might have a magnitude of 10,000 m^3/year by based on extrapolation of very few data. This discharge might be relatively small compared to the estimated volume of litter in the North Sea of 100.000 m^3 of which about 20,000 ton/year (about 30,000 m^3/year) from navigation only. However, the life time of the plastic litter in the North Sea should be considered as well if compares with the amount of litter present at a certain time.

Missing data
Contractors and municipalities remove large volumes of floating debris after a flood, but very few reliable data on quantities are publicized. Few preliminary data were found on the transport of plastic litter in a foil like shapes and on the bed load transport of plastic litter. Data on clean-ups give a rough indication of the total volume but no percentage of plastic litter and no specification of the composition of plastic litter and its source. Data is also missing on the transport of litter in the harbour-regions of Dordrecht to Europoort and Amsterdam to Ijmuiden and Terneuzen and Flushing.

Data is missing completely on nano and micro plastic particles (such as fibres) in the discharge of sewage treatment plants in the catchment areas of the considered rivers.

In this desk study the data search on mainly the internet was time consuming and therefore the search for data is not exhaustive. In a continuation of the study more relevant might be found in the corners of the internet or by direct consultation of the involved organizations.

Legislation and governance

The Marine Strategy Framework Directive (MSFD) installed to ensure Good Environmental Status (GES) by 2020 includes the descriptor 'Marine Litter' (descriptor 10). National authorities in the Netherlands are implementing the MSFD and need to provide the European Commission with input on the amounts of debris in the Dutch marine environment.

For freshwater, one of the main policy instruments is the Water Framework Directive (WFD) which aims to achieve good chemical and ecological status by the year 2015. The WFD however does not include plastic litter in determining this good status.

The enforcement of laws and regulations focused on the prevention of litter in the environment is insufficient to be effective in reducing the quantities of plastic litter in the river systems.

The removal of plastic litter in a river system is a task for land owners (for example nature conservation organizations owns areas in flood plains), municipalities, water boards, the national or at ministerial level, for example Rijkwaterstaat, and some private organizations. Improved legislation might result in a more transparent and effective distribution of tasks. An example is the need to harmonize the payment method for issue of household waste from ships in different countries.

8.2 Recommendations

The desk study has resulted in several recommendations aiming at a reduction of the transport of plastic litter in the Rhine, Meuse and Scheldt Rivers. A reduction requires appropriate management actions based on up to date and in depth knowledge of transport of plastic litter in alluvial river systems.

Co-operation and regulations
The following actions are recommended to strengthen cooperation and enforcement of unified regulatons:

- To extend international harmonized regulations concerning production of plastic litter, monitoring programs of plastic litter and prevention of plastic litter in a riverine environment.
- To improve enforcement of laws and regulations regarding litter in a river system. At present enforcement is in some aspects weak partly because of complex co-operation between organizations.
- To extend the international co-operation to reduce the transport of litter in river systems flowing via several countries.

Data on transport of plastic litter in rivers
The following actions are recommended to improve the knowledge on the transport of plastic litter in rivers

- To setup an international database on volumes of removed debris by contractors and by volunteers in clean-ups. This database should also include data on costs involved in removing and collecting litter. It is recommended to extend the site Scheldt Monitor with data on litter and floating debris.
- To set up an international inventory of sources of plastic litter in the river system and methods to attribute collected litter to a certain source.
- To execute field measurements of plastic litter transport in rivers, for example during floods.
- To investigate the contribution of sewerage treatment plants to the transport of plastic litter in rivers.

Knowledge on transport of plastic litter in rivers
The following actions aiming at improving the knowledge on plastic litter are recommended

- Study the transport of plastic litter with shapes like foils in rivers and the role of turbulence intensities and the transport of microplastics, to explore the methods for identification of the sources of plastic litter items,
- To survey the presence of plastic litter in a river bed, especially in the river bed upstream of hydraulic structures
- To expand the data collection on plastic litter, especially data on plastic litter in the rivers Rhine and Ems
- To inventory the knowledge on the transport of plastic litter in river basins in other countries. This inventory includes also the experiences with measures to reduce the amount of plastic litter in rivers.

Measures
The following measures are recommended to reduce the amount of plastic litter in rivers:

- A cost free issue of litter in a garbage transfer stations in a catchment area will reduce the frequency of illegal dumping of litter in a floodplain.
- To increase the availability of well maintained waste bins and containers in nature reserves in the floodplain that are open for public.
- Start discussions with industries in the catchment to reduce their emissions of plastic litter and to inform industries about effective measures. An example is to convince industries to stimulate their staff to participate in a clean up of river banks and adjacent flood plains.
- To raise awareness for the envuironmental pollution by plastic litter.

9 Literature

9.1 Marine litter

Feldkamp, S.D., Costa, D.P., and Dekrey. G.K. 1989. Energetic and behavioral effects of net entanglement on juvenile northern fur seals, *Callorhinus ursinus*. Fish Bull 87:85-94.(from Derraik, 2002)

Rotterdam Havenafvalplan (2009) Port of Rotterdam, pp. 35

Leslie, H., M.D van der Meulen, F.M. Kleissen and A.D. Vethaak (2011) Microplastic Litter in the Dutch Marine Environment. Providing facts and analysis for Dutch policymakers concerned with marine microplastic litter. Deltares, report 1203772-000.

Ryan, P.G., Moore, C.J., Van Franeker, J.A., Moloney, C.L. (2009) Monitoring the abundance of plastic debris in the marine environment, Phil Trans R Soc B, 364:1999-2012, doi: 10.1098/rstb.2008.0207

Teuten, E.L., Saquing, J.M. Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Björn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P.H., Tana, T.S., Prudente, M., Boonyatumanond, R., Zakaria, M.P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M. and Takada, H. (2009) Transport and release of chemicals from plastics to the environment and to wildlife, Phil Trans R Soc B, 364:2027-2045 doi: 10.1098/rstb.2008.0284

Bergmann, M., Klages, M. (2012, *in press*) Increase of litter at the Arctic deep-sea observatory HAUSGARTEN, Mar Pol Bull

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S. (2011) Microplastics as contaminants in the marine environment: a review, Mar Pol Bull, 2588-2597

Derraik, J. G. B. (2002) The pollution of the marine environment by plastic debris: a review, Mar Pol Bull, 44:842-852

Lattin, G.L., Moore, C.J., Zellers, A.F., Moore, S.L., Weisberg, S.B. (2004) A comparison of neustonic plastic and zooplankton at different depths near the southern California shore, Mar Pol Bull, 291-294

Website IMO: http://www.imo.org/ourwork/environment/pollutionprevention/garbage/Pages/Default.aspx

OSPAR (1995) Summary Record of the Oslo and Paris Conventi ons for the Preventi on of Marine Polluti on Working Group on Impacts on the Marine Environment (IMPACT) Group, IMPACT 95/14/1-E. (from Mouat et al., 2010)

Galgani, F., Leaute, J.P., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., Goraguer, H., Latrouite, D., Andral, B., Cadiou, Y., Mahe, J.C., Poulard, J.C., Nerisson, P. (2000) Litter on the sea floor along European Coasts, Mar Pol Bull, 40(6): 516-527

Fishing for Litter, 2006/2007 datasheet, http://www.fishingforlitter.org/WebData/Files/List%20monitored%20marine%20litter%202006%20and%202007.pdf

Thiel, M., Hinojosa, I.A., Joschko, T., Gutow, L. (2004) Spatio-temporal distribution of floating objects in the German Bight (North Sea), J Sea Res, 65:368-379

UNEP (2009). Marine Litter: A Global Challenge. United Nations Environment Programme

Ardea Milö (2001) Marine Litter – trash that kills, Risbergs Udavalla, Sweden

UNESCO, 1994

Website MARPOL http://www.imo.org/ourwork/environment/pollutionprevention/garbage/Pages/Default.aspx

FAO (2009) Abandoned, lost, or otherwise discarded fishing gear, FAO consultants, pp 139

Mouat, J., Lopez Lozano, R., Bateson, H., (2010) Economic impacts of marine litter, KIMO report, pp 117

Derraik et al., 2010

Jacobsen, J.K., Massey, L., Gulland, F. (2010) Fatal ingestion of floating net debris by two sperm whales (Physeter macrocephalus), Mar Pol Bull, 60:765-767

Van Franeker, J.A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P.L., Heubeck, M., Jenseni, J.K., Le Guillo, G., Olsen, B., Olsen, K. O., Pederser, J., Stienen, E.W.M., Turner, D.M. (2011) Monitoring plastic ingestion by the northern fulmar Fulmarus glacialis in the North Sea, 159:2609-2615

Cheshire, A.C., Adler, E., Barbière, J., Cohen, Y., Evans, S., Jarayabhand, S., Jeft ic, L., Jung, R.T., Kinsey, S., Kusui, E.T., Lavine, I., Manyara, P., Oosterbaan, L., Pereira, M.A., Sheavly, S., Tkalin, A., Varadarajan, S., Wenneker, B. and Westphalen, G. (2009) UNEP/IOC Guidelines on Survey and Monitoring of Marine Litt er. UNEP Regional Seas Reports and Studies, No. 186; IOC Technical Serious No. 83.(from Mouat et al., 2010)

Carpenter, E. J., Anderson, S. J., Harvey, G. R., Miklas, H. P. & Peck, B. P. (1972). Polystyrene spherules in coastal waters. Science, N.Y., 178 :749-750

SWD (2012) Commission staff working document, overview of EU policies, legislation and initiatives related to marine litter, Brussels, pp. 33

9.2 Monitoring methods

Sprengler, A., Costa, M.F. (2008) Methods applied in studies of benthic marine debris, 56:226-230

Van Franeker, J.A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P.L., Heubeck, M., Jenseni, J.K., Le Guillo, G., Olsen, B., Olsen, K. O., Pederser, J., Stienen, E.W.M., Turner, D.M. (2011) Monitoring plastic ingestion by the northern fulmar Fulmarus glacialis in the North Sea, 159:2609-2615

OSPAR (2007) OSPAR Pilot Project on Monitoring Marine Beach Litter: monitoring of marine litter in the OSPAR region, pp. 75

Veenstra and Chopard (2012)

Van Paassen, J. (2010) Plastic afval in rivieren, onderzoek naar hoeveelheid en samenstelling, University Utrecht, 47 pp

(Moore, 2005)

9.3 Microplastics

Besseling, E., A. Wegner, E. Foekema, M. Van Den Heuvel-Greve, A. A. Koelmans (2013) Effects of microplastic on fitness and PCB bioaccumulation by the lugworm Arenicola marina (L.) Environ. Sci. Technol., 47 (1), pp 593–600

Browne, M.A, P. Crump, S.J.Niven, E. Teutens, A. Tonkin, T. Galloway, R. Thompson (2011) Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. Environ. Sci. Technol., vol 45, pp. 9175–9179

Gouin, T., N. Roche, R. Lohmnan, G. Hodges (2011) A Thermodynamic approach for assessing the environmental exposure of chemicals absorbed to micro-plastic. Environ. Sci. Technol vol. 45, pp. 1466-1472.

Gregory, M.R. (1996) Plastic 'Scrubbers' in Hand Cleansers: a Further (and Minor) Source for Marine Pollution Identified. Marine Pollution Bulletin. Vol. 32, No. 12, pp. 867-871,

Hidalgo-Ruz,V., L. Gutow, R. C. Thompson, M. Thiel (2012) Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. Environ. Sci. Technol., vol. 46, pp.3060−3075

Leslie, H., M. Moester, M.de Kreuk, D. Vethaak (2012) Verkennende studie naar lozing van microplastics door rwzi's. H_2O vol 14/15, pp 45-47.

Leslie, H., M.D van der Meulen, F.M. Kleissen and A.D. Vethaak (2011) Microplastic Litter in the Dutch Marine Environment. Providing facts and analysis for Dutch policymakers concerned with marine microplastic litter. Deltares, report 1203772-000.

Markus, A.A , R.W.P.M. Laane, J.R. Parsons, E.W.M. Roex, G.C.M. Kenter (in prep.) Predicted contribution of nanoparticles (Zn, Ti, Ag) to the annual metal load in two Dutch rivers.

9.4 River Meuse

Limburgs Landschap, Jaarverslag 2009

Paassen, J. (december 2010) Plastic afval in rivieren, onderzoek naar hoeveelheid en samenstelling, University Utrecht, 47 pp

Rijkswaterstaat (2006) Richtlijn zwerfvuil

Steegemans, P. (26 mei 2008) Projectplan Integrale aanpak zwerfafval binnen het beheersgebied van het Waterschap Roer en Overmaas, Waterschap Roer en Overmaas, Sittard, 14 pp..

Technische Adviescommissie voor de Waterkeringen, (August 1995) Druk op de dijken 1995, Delft,

Valkman, R. (2012) Richtlijnenboek Watermanagement Rijkswaterstaat Limburg, TAUW, Deventer, version 1.1, 43 pp

Waltje, E (31 augustus 2007) Aanpak zwerfafvalproblematiek in het beheersgebied van het Waterschap Roer en Overmaas, Saxion Hogescholen Deventer, 31 augustus 2007, 51 pp

9.5 River Rhine

OSPAR, Geography. hydrography and climate, chapter 2, www.ospar.org,

Centrale Commissie voor de Rijnvaart (1996) Verdrag inzage de inzameling, afgifte en inname van afval in de Rijn- en binnenvaart, Centrale Commissie voor de Rijnvaart, Strasbourg, edition 2020, 75 pp

Koopmans, M. (5 november 2009) Financiering van de inzameling van afvalstoffen, direct of indirect Ministerie Verkeer en Waterstaat, Den Haag

Technische Adviescommissie voor de Waterkeringen, (August 1995) Druk op de dijken 1995, Delft.

ENW-Techniek, 11 March 2011, Waarnemingen Hoogwater 2011, STOWA, project 474.020, Utrecht

9.6 River Scheldt

Gonsaeles, G. and F. Maes (1999) Gegevensverzameling over de productie afgifte en inzameling van scheepsbedrijfsafval door de binnenvaart in vier Vlaamse zeehavens en langs de Vlaamse waterwegen, ICOWARE Maritiem instituut van de Universiteit van Gent.

Maes F., G. Gonsaeles and Buyse (approximately 2001), Studie van de afvalstromen afkomstig van de scheepvaart, binnenvaart en goederenbehandeling in de havens van Antwerpen, Gent, Oostende en Zeebrugge, synthese, Maritiem Instituut van de Universiteit van Gent,

De Gazet van Antwerpen is a newspaper for Antwerpen and surroundings

Port of Antwerp, Annual report 2008

Provincial Instituut voor Hygiene (2004) Beleidsovereenkomst natuurlijke entiteiten stad Antwerpen

OVAM - Openbare Vlaamse Afvalstoffenmaatschappij (March 2011) Vlaams afvalbeheersplan voor de binnenvaart 2011 – 2015,

Glossary

The following definitions and abbreviations have been used in this report.

Abbreviation or concept	Description
Blue Flag	Voluntary eco-label for beaches and marinas.
Debris	Loose material consisting of all kinds of material (metal, plastic, rubber) including parts of vegetation transported in a river. In this report items larger than 5 mm are part of the macro fraction. Three transport modes of debris are distinguished in rivers: floating, in suspension and bed load
Flood plain	At high river discharges a river channel overflows its banks on to the adjacent land, called flood plain. The extend of a flood plain is determined by the design safety level and the topography (for example 1 flood in 100 years on average or 1 flood in 1250 years on average)
IMC	International Meuse Commission
KIMO	Kommunenes Internasjonale Miljøorganisajon; founded by local municipalities with a shared concern for the state of the environment (Website KIMO).
Litter	Waste products that have been disposed of improperly, without consent, in an inappropriate location (Wikipedia). In a river inappropriate locations are floodplains, banks and dykes,
Macroplastics	Plastic particles > 5 mm in diameter (by a sieve). It is mentioned that in GEF/STAP report another criterion is proposed: plastic particles > 1 mm and < 100 mm.
Microplastics	Plastic particles ≤ to 5 mm in diameter and measured by sieving.
North Sea Foundation (Stichting de Noordzee)	Non-governmental organisation that aims to achieve sustainable use of the North Sea. Focal points are clean shipping, sustainable fisheries, good fish, space for nature and litter free seas and beaches (Website Stichting de Noordzee).
OSPAR	Oslo Paris Convention; current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic (Website OSPAR).
Plastic	A synthetic molecule consisting of polymer chains. Examples are polypropylene, polyethylene and polystyrene.
PRF	Port reception facilities of waste from ships
Primary microplastics	Microplastics which are intentionally produced either for direct use or as precursors to other products. Examples include pre-production plastic pellets, industrial abrasives, cosmetics, plastics used in rotomilling, and other consumer product uses.
STP	Sewage treatment plant
Secondary microplastics	Microplastics originating from the degradation of larger plastic particles for example through mechanical, thermal and UV-stress)
Ton	Metric ton, 1 ton = 1000 kg
Waterboard	Dutch governmental body responsible for managing dikes, water levels and water quality in a designated area.

A Background of marine litter

A.1 Classification

Plastics are polymer chains that are formed either by joining monomers or by creating a free radical monomer which produces a long chain polymer (Leslie et al., 2011). Macro plastics are large plastic particles that enter the sea from rivers and other terrestrial sources as well as from direct sea-based sources such as shipping (post-consumer waste and spillage), fishing equipment, tourism and offshore industry There is no clear size range for macro plastics, however, since particles smaller than 5 mm are termed ‘microplastics’, everything larger than that is considered macro plastic in this study. Furthermore in the GEF/STAP report an other criterion is proposed: plastic particles > 1 mm and < 100 mm are macro plastic particles. It this report we consider a classification based on the transportation mode of plastic particles in a river (floating, in suspension and as bed load). The transportation mode of a piece of plastic can change by fouling however, which complicates the application of such a criterion.

A.2 Lifetime

Table A.1. gives an impression of how long different types of waste take to break down in the marine environment. In a river basin the period after different types of litter disintegrate varies also, for example: an apple only 14 days, an aluminium can extremely long period, a polyester bottle 5 to 10 years and cigarette butts 2 years (Nederland Schoon). These examples illustrate that plastic litter remains relatively long periods in the environment.

Tabel A.1 Indication of time taken for typical objects to dissolve at sea
http://www.imo.org/ourwork/environment/pollutionprevention/garbage/Pages/Default.aspx

Time taken for objects to dissolve at sea	
Paper bus ticket	2-4 weeks
Cotton cloth	1-5 months
Rope	3-14 months
Woollen cloth	1 year
Painted wood	13 years
Tin can	100 years
Aluminium can	200-500 years
Plastic bottle	450 years

Source: Hellenic Marine Environment Protection Association (HELMEPA)

A.3 Primary and secondary microplastics

Microplastics can be divided into primary and secondary microplastics. Primary microplastics are intentionally produced either for direct use, or as precursors to other products. They originate from pre-production plastic pellets, industrial abrasives, cosmetics, plastics used in rotomilling, and other consumer products. Secondary microplastics are created by the fragmentation of macro plastics as it degrades.

Both types are relevant in this study, especially since treated sewage effluents have been shown to emit primary microplastics into fresh water systems. Currently, secondary microplastics are more abundantly found in the environment, however the contribution of primary microplastics is thought to increase as a result of increased welfare worldwide, and its associated increase in consumption of cosmetics, synthetic clothing and industrial plastics.

A.4 Additives

To give plastics the properties we require (heat resistance, resistance against oxidative damage and microbial degradation), additives are added to the polymers. These make plastics flexible, extremely durable and resistant to oxidation and decomposition. Commonly used additives include phthalates,phenols (like bisphenol A used producing polycarbonate polymers) and flame retardants. These chemicals can cause endocrine disruption in organisms (Leslie et al., 2011) and may affect reproduction, development and cause carcinogenesis (Cole et al., 2011). Exposure of humans to bisphenol A has been associated with chronic health effects, mainly heart disease, diabetes and changes in hormone levels (Cole et al., 2011). On top of this it has been described in numerous studies that plastics can absorb persistant bioaccumulative and toxic substances including persistent organic pollutants (eg Teuten et al. 2009). Further knowledge on the potential of plastics to absorb, transport and release chemical contaminants has to be developed in order to properly assess the potential harm and added risk they may cause at each level.

A.5 Presence throughout water system

Plastics are found in all parts of the water system; on the surface, in the water column, but also in sediments and biota.

Large plastic particles, macro plastics, can be dispersed over long distances due to their buoyancy, however, it is thought that plastic debris eventually ends up in sediment (Derraik, 2002). This is confirmed by research conducted by Lattin et al., (2004) who found that most plastics are present in the epibenthic part of the water column. Macro plastics eventually degrade down to microplastics. The residence time of these smaller particles in the sea surface layer is relatively short, in the order of weeks or months (Derraik, 2002).

Plastics are even found in the deep sea and the Arctic. In the latter, at a depth of 2500 m, an increase in the amount of litter was demonstrated from the years 2002 to 2011. The litter consisted mainly of plastic bags and the densities of this litter ranged from 3635 to 7710 particles per km^2 (Bergmann & Klages, 2012, in press.).

A.6 Estimate of volume of litter in North Sea

Data for the amount of debris currently floating in the world's seas and oceans are commonly based on estimates on the amount already in the ocean, or on determining how much is added each year and through marine litter monitoring surveys.

Estimates on the amount of debris in the oceans are complex while different assessment methods are being used, and therefore reliable estimates are difficult to obtain. In 1982 the estimation was that 8 million items of litter are entering the oceans every day, however, this number may need to be multiplied several fold taking into account the increasing production of plastics. In 2011 the annual global production of plastics was 280 million tons, with an estimated yearly increase of about 4% until 2016 (Press release Plastics Europe, welk jaar?). It has been estimated that more than 10% of these plastics eventually ends up in the oceans (Bergmann & Klages, 2012, in press). Europe produced 21,7% of the global production total, being 57 million tons of plastic in 2010 (Plastic-The Facts 2011) and created 24.7 million tons of consumer plastic waste (Leslie et al., 2011). Production and consumption patterns however are geographically separated, where production is typical for developing countries and consumption and disposal are global issues.

The OSPAR commission suggests that approximately 20 000 tonnes waste dumped by ships enters the North Sea on an annual basis (OSPAR, 1995 uit KIMO 2010). A density of litter of 1.56 items per hectare was found by trawling cruises, out of which 75% was plastic (Galgani et al., 2000). The numbers for the percentage plastics and number of items found differ among the locations sampled, but those of the North Sea (156 items/km^2) are comparable to numbers in other area along the European coast (126 items/km^2 in the Baltic Sea; 528 items/km^2 in the Celtic Sea; 142 items/km^2 in the Bay of Biscay; 143 items/km^2 in the Gulf or Lion; 1935 items/km^2 in the North-West Mediterranean; 229 items/km^2 in East Corsica and 378 items/km^2 in the Adriatic Sea). It was also estimated that the majority of the litter (70%) in the North Sea sinks to the seafloor, 15% floats on the sea surface and 15% washes up on shore (Galgani et al., 2000). This litter probably mainly originates from fisheries. Galgani et al., (2000) also found two high-concentration zones; one 200 km west of Denmark, and a smaller one in the western part of the North Sea.

In the Dutch Fishing for Litter campaign by KIMO, a project in which fishermen were financially compensated for fishing on waste in the marine environment, collected approximately 500 tonnes of litter from the years 2000 to 2006. In the year 2006, the total amount of waste collected in the 10 participating harbours in the Netherlands was 204 tonnes and in 2007 this increased to 220 tonnes. The main materials found were made out of rubber and plastics (Fishing for Litter, 2006/2007 datasheet).

In 2011 the ‘Fishing for Litter’ program retrieved over 400 tons of waste that was delivered back into Dutch harbours (KIMO annual report 2011).

Litter in the German Bight, north of the Dutch Continental Shelf, is also dominated by plastics. However, the main source here is thought to be the shipping industry (Thiel et al., 2011). There was no indication that riverine input was a significant source of litter in this area.

The total volume can be estimated roughly assuming a plastic particle has a volume of1 litres on average and the North Sea covers an area of 750,000 km^2 and using the data published by (Galgani et al 2000):

1.56 items/hectare*0.75* 75 million hectare * 0,001 m^3 = 90,000 m^3 plastic litter in the North Sea

This indicates that a total volume of plastic litter of about 100,000 m^3.

A.7 Sources

The sources of plastic litter have been divided in sources of macro plastic and sources of micro plastic.

A.7.1 Sources of macro plastics

UNEP published an overview for the debris that floats on the surface (see figure 3.1) demonstrating that sources of debris are both point- and non-point sources and are present on land, in coastal areas and off-shore.

Table 1. Types and Sources of Floatable Debris

Source	Examples of Debris Released
Storm Water Discharges	Street litter (e.g., cigarette butts, filters, and filter elements), medical items (i.e., syringes), resin pellets, food packaging, beverage containers, and other material from storm drains, ditches, or runoff
Combined Sewer Overflows	Street litter, sewage-related items (condoms, tampons, applicators), medical items (i.e., syringes), resin pellets, and other material from storm drains, ditches, or runoff
Beachgoers and Other Nonpoint Sources	Food packaging, beverage containers, cigarette butts, toys, sewage, pieces of wood and siding from construction projects, and trash (e.g., beverage containers, food packaging) left behind by workers in forestry, agriculture, construction, and mining
Ships and Other Vessels	Fishing equipment (e.g., nets, lures, lines, bait boxes, ropes, and rods), strapping bands, light sticks (used by fishermen to light up fishing lines and recreational divers), plastic salt bags, galley wastes, household trash, plastic bags and sheeting, and beverage yokes (six pack rings for beverage containers)
Solid Waste Disposal and Landfills	Materials such as garbage and medical waste
Offshore Mineral and Oil and Gas Exploration	Data-recording tape, plastic drill pipe thread protectors, hard hats, gloves, and 55-gallon drums
Industrial Activities	Plastic pellets and other materials
Illegal Dumping or Littering	Food packaging, beverage containers, cigarette butts, appliances, electronics, and ocean and street litter

Figure 3.1 An overview of the types and sources of floatable debris (UNEP, 2009)

Shipping

The shipping industry is thought to be one of the main contributors to the waste in the world's seas and oceans. Sunken ships are often a temporary source of floating debris and debris on the seafloor. It is estimated that the total input of marine litter into oceans on a global scale is approximately 6.4 million tonnes per year, out of which 5.6 million tonnes is attributed to the shipping industry (Ardena Milo, 2001). Estimates from 1982 state that merchant ships dump 639 000 plastic containers every day around the world (Derraik, 2002). Furthermore, recreational fishing and boats contribute considerably to marine debris in the USA, disposing 52% of all litter dumped in US waters (UNESCO, 1994).

Recently, Annex V of the MARPOL (International Convention for the Prevention of Pollution from Ships) was revised and now prohibits the discharge of all garbage anywhere into the sea. This includes all food, domestic and operational waste. The North Sea is designated as Special Area under the MARPOL convention due to the problems associated with the heavy maritime traffic (Website MARPOL).

Fisheries

Fishermen loose gear on a daily basis, mainly because their nets get caught behind shipwrecks or other hard materials on the seafloor. Due to the fact that these synthetic nets are a trap for marine organisms, even though they are not actively trawled, they are often termed 'ghost nets'. It is estimated that approximately 52 metric tons of fishing gear are lost in on annual basis (Veenstra & Churnside, 2012).

Abandoned, lost or otherwise discarded fishing gear has been recognized internationally as a major problem and the issue has been raised at the level of the United Nations General Assembly.

The FAO (United Nations Food and Agricultural Organisation) has produced estimates of the loss of nets in the Northeast Atlantic fisheries sector and found that the percentage loss of nets per boat per year varies among countries and type of fisheries. Estimates for the North Sea & Northeast Atlantic for bottom-set gillnets range from 0.02 to 0.09 % nets lost per boat per year (FAO, 2009). There are no data available for the Netherlands specifically, however, in neighbouring countries such as the UK, all coastal fisheries combined loose about 35 km of net per boat per year (FAO, 2009).

Terrestrial sources

The contribution of rivers and terrestrial sources to litter in the marine environment is thought to be considerable.

In a harbour in Canada, researchers found that 62% of the total amount of litter resulted from recreation and other land-based origins (Derraik, 2002). In terms of plastic litter, terrestrial sources contribute approximately 80% of the total amount of plastic litter found in the marine environment (Cole et al., 2012). This also includes microplastics from primary sources. Data from New Zealand beaches underline the idea that land-based sources contribute considerably to plastics in the environment; the greatest concentration of raw plastic granules were found on the coast close to industrial centers (Derraik, 2002).

A.7.2 Sources of microplastics

As stated before, microplastics can be divided in primary and secondary microplastics, the latter category being a degradation product of macro plastics, originating from all kinds of sources. The main sources of primary microplastics are supposed to be two different categories of consumer products, namely cosmetics and textiles. Besides spillage of pre-production pellets, industrial applications like air blast cleaning media are possible sources.

Cosmetics

Microplastics are added to several cosmetic products like hand cleaners, liquid soaps, shower gels and tooth paste. These particles were already found to be added to these products for some 20 years ago (Gregory, 1996), but have drawn a lot of attention during the last few years, as they are found to be ubiquitous in all environmental compartments, including biota (Leslie et al., 2011). These particles have a cleansing effect and are cheaper than other sources of small particles as sand or clay.

Only little information is available about the amount of microplastics used in cosmetics, and consequently the amount that ends up in riverine systems via Sewage Treatment Plants (STPs). Estimates of the amount of polyethylene microplastics used in liquid soap are only available for the American market based on the amount of liquid soap sold, the percentage of companies that use micro plastic beads in their products, the amount of microplastics used in liquid soap, and the amount of liquid soap used per person. This results in a per capita consumption for the U.S. population of approximately 2.4 mg/day (Gouin et al., 2011). At this moment it is unknown if this figure also holds for the European situation.

Based on the population living in the Rhine and Meuse basins, respectively 6.5 and 3.5 million inhabitants (Markus et al., in prep) the amount of microplastics used results in 15,6 kg/day for the Rhine basin and 8,4 kg/day for the Meuse basin.

At the moment not much is known about the removal efficiency of microplastics by STPs. A preliminary study of VU Amsterdam, TU Delft and Deltares has shown that STPs withhold approximately 90% of the microplastics that were present in the sewage influent (Leslie et al., 2012). These measurements will be extended by research on a suite of STPs by VU-IVM and Deltares in 2013. In this way, more information will be available on the removal efficiency of the different treatment methods. Taking the removal efficiency of 90% as a default, this results in 1.5 kg/day or about 0.7 m^3/year entering the Rhine basin and 0.8 kg/day or 0.4 m^3/year entering the Meuse basin on a daily use, due to the presence of microplastics in liquid soap.

Because of the public pressure in the Netherlands, some commercial chains recently ended the sale of cosmetics containing micro beads. Also Unilever, a main producer of micro beads announced recently their production stop of cosmetics containing micro beads in the Netherlands by mid 2013 and a global ban in 2015 (http://nos.nl/artikel/455952-geen-microbeads-meer-bij-unilever.html). These initiatives probably cause a diminished emission of microplastics to the aquatic environment in the future.

Textiles
Recent studies have shown that a potentially relevant source of microplastics appears to be through sewage contaminated by fibers from washing clothes. Experiments sampling wastewater from domestic washing machines demonstrated that a single garment can produce >1900 fibers per wash. This suggests that a large proportion of micro plastic fibers found in both riverine and marine environments may be derived from sewage as a consequence of washing of clothes. As the human population grows and people use more synthetic textiles, contamination of habitats by microfibers originating from textiles is likely to increase (Browne et al., 2011).

Air blasting
Not much is known about the amount and routes of microplastics used in air blasting cleaning media. Although the total amount of particles used in these applications is probably smaller than the amounts used for cosmetics and textiles, this may still be an important emission route for microplastics as a larger part of these particles will directly enter the environment, without passing a STP, as a result of the outdoor character of these applications. Plastic particles which are used in air blasting may present an additional hazard to aquatic life because they become contaminated with heavy metals when used for stripping paint from metallic surfaces and cleaning engine parts. When such contaminated particles reach the aquatic environment, heavy metals or other contaminants in these particles could potentially be taken in by filter feeding organisms and ultimately other passed onto organisms in the food chain (Gregory, 1996). I thought most of these micros for sandblasting are recycled/reused, but there may be some spillage ofcourse!

A.8 Effects of macro plastics on biota

For plastics, the effects depend on the size and shape of the particles present in the marine environment. These effects are mainly entanglement and ingestion, however other effects have also been documented.

Entanglement
Entanglement has been reported in 130 species of marine animals, mainly birds, seals and cetaceans (KIMO, 2010).
Once an animal is entangled, it can drown, the plastic may cause wounds and may affect the mobility of the animal in terms of catching prey or avoiding predators (Derraik, 2002). Furthermore, a study on northern seals by Feldkamp et al., (1989) (uit Derraik, 2002) demonstrated that entanglement in fishing nets can cause a 4-fold increase in the demand of food consumption while traveling. Several studies (reviewed by Derraik, 2002) link population declines in species of fur seal to entanglement in plastics. Furthermore, in the German Bight, entanglement accounts for 13-29% of the mortality rates in sea birds (gannets) (Derraik, 2002). Whales can also get entangled in fish nets, since they sometimes prey on schools of fish that are being caught (Derraik, 2002).

Ingestion
To date ingestion of marine litter has been reported in 111 species of seabird, 31 marine mammal species and 26 species of cetaceans (KIMO, 2010).
Harmful effects from ingestion of plastic debris are associated with blockages of gastric enzyme secretion, blockages of the intestinal tract, diminished feeding stimulus and hormonal imbalances (Derraik et al., 2010). These processes can reduce food uptake, cause reproductive failures and can lead to internal injuries and death. The most well-known

animals associated with plastic ingestion are Northern fulmars that are used by OSPAR and the 'Planbureau voor de Leefomgeving' as an EcoQO for the status of plastic waste in the oceans. Van Franeker (2011) studied the stomach content of almost 1300 birds in the North Sea, 95% of which had plastics in their stomach. The ecological quality benchmark for OSPAR allows only a 10% maximum score.A study by Jacobsen et al., (2010) demonstrated that two sperm whales stranded in California had large amounts of plastic debris in their stomach. There were 134 different types of nets of varying sizes and the cause of death was thought to be gastric impaction.

In 1973 a study on fish in the Bristol Channel found that 21% of flounders (*Platichthys flesus*) caught, and 25% of sea snails (Laparis laparis) contained micro plastic pellets (Kartar et al., 1976 from Derraik et al., 2010). Data from a study in the US show similar numbers; in some species of fish up to a third of the individuals has plastics in their stomachs (Carpenter et al., from Derraik et al., 2010). Experiments where domestic chickens were fed with polyethylene pellets support the thesis that ingested plastic decrease the storage volume of the stomach, and thus food consumption. This eventually reduces fitness (Derraik, 2002).

One commercially interesting species to the Netherlands, the mussel Mytilus edulis, also ingests plastic particles. Van Moos et al., (2012) exposed mussels to high-density polyethylene particles (0-80 µm) for 96 hours and found that microplastics were taken up into the gills and digestive gland. Histological research demonstrated that the plastic particles were taken up into the stomach and transported to the digestive gland, causing granulocytomas after 6 hours. For an overview of microplastics in biota, see Leslie et al., 2011.

A.9 Effects of plasticers

As plastic particles degrade, plastic additives ('plasticers') are released into the environment. Due to their large surface-area-to-volume ration of microplastics (Cole et al., 2011) leaching of additives after ingestion may occur at a higher rate than with larger plastic particles. Plastic particles may also influence the uptake of other contaminants in different ways. A recent study has shown that sediment with a low dose of polystyrene particles increased bioaccumulation of PCBs by the bentic marine worm *Arenicola marina* by a factor 1.1 - 3.6, an effect that was significant for ΣPCBs and several individual congeners. At higher doses of plastic particles in the sediment bioaccumulation decreased compared to the low dose (Besseling et al., 2012)

A.10 Economic impacts of marine litter

A study on the economic impacts of marine litter was conducted by KIMO in 2010. The research looked at the whole of the Northeast Atlantic, including the Netherlands.

Municipalities

Results of the study for the Netherlands demonstrate that the most common reason for municipalities to undertake beach cleaning was to maintain and enhance tourism in the area (92.3%), followed by the pursuit of Blue Flag and public health (46%) and the risk to local business (38%). Approximately two thirds of the municipalities cooperated with external parties in the clean ups.

The majority of the municipalities surveyed used a combination of mechanical and manual methods for cleaning up the beach.

In table 3.2the costs of marine litter are summarised for the Netherlands, Belgium and the UK.

Table 3.2 Estimated costs of marine litter for the Netherlands, Belgium and United Kingdom

Country	**Total cost of beach clean-up to municipalities (€)**	**Average cost per municipality per year (€)**	**# of municipalities participated (-)**	**Average stretch cleaned per municipality (km)**	**Quantity removed (ton)**
Netherlands and Belgium	10,400,000	226,541	10	6.2	724 (in 6 municipalities)
UK (including Scotland)	18,000,000	145,587	31	17.5	21,757 (in 19 municipalities)

The table 3.3 demonstrates that the yearly average costs for the removal of marine litter on beaches are higher in the Netherlands than in the UK, even though the average stretch cleaned is smaller.

UK municipalities (based on 27 municipalities) spend € 159,497 per year breaking down waste and preventing litter. Maintenance costs amounted to € 74,838 and the costs for litter bins to € 48,423. Compared to the Netherlands that spends … and ….

For other countries around the North Sea only few responses were gathered. The results are demonstrated in table 3.3below.

Table 3.3 Cost of beach litter clean up

Country	**# of responses**	**Total cost of beach litter removal per year (€)**	**Total distance where litter is removed (km)**	**Cost of beach litter removal per km per year (€)**
Denmark	1	6,701	18	372
Ireland	1	89,950-102,800	8	11,244 -12,850
Portugal	3	318,170	15	8,278 – 31,768
Spain	2	656,518	12	38,190 -87,500
Sweden	2	64,114	157	213 – 4,580

Other organizations

To study the economic costs of marine litter to other organisations, KIMO focused on the United Kingdom (UK). Even though the litter problem is likely to be different in the UK and in the Netherlands, values for the UK and Scotland are taken as an estimate for those of the Netherlands. In table 3.4 an overview is given of the costs to the different sectors in the UK.

Table 3.4 Overview of costs for different sectors in United Kingdom

Sector	**Average costs per year UK/Scotland (€)**
Voluntary organisations	16.23 (per volunteer)
Tourism	unknown
Sea fisheries	11,700,000-13,000,000*
Aquaculture	580 (per producer)
Harbours and marinas	8,034 (per harbour)
Rescue services	830,000-2,189,000
Agriculture	841 (per crofter)
Power stations, seawater abstractors and water authorities	unknown

* This is equivalent to 5% of the revenues of the affected fisheries.

Voluntary organisations
In the UK, each volunteer in beach cleaning campaigns contributed € 16,23 on average of their time each year. For one voluntary beach clean up campaign, for example done by 300 volunteers in the Netherlands, costs would be € 4,869 for a single campaign.

Tourism
In the UK, approximately 16.5-17.4 million tourists are specifically attracted by the beach or coastline. These tourists spend an estimated € 1.8 billion while visiting coastal locations. In the Netherlands, this is …. Translating the loss of value of a coastal area to a decrease in revenues from tourism has, however, not been done yet.

Sea fisheries
Fisheries in Scotland are impacted by marine litter. Restricted catches due to marine litter, contaminated catch and snagging of nets on debris on the seabed were reported by 86%, 82% and 95% of respondents respectively. Marine litter costs the Scottish fisheries industry between € 11,7 and € 13 million a year, equivalent up to 5% of the total revenue of the fisheries affected.

Aquaculture
Aquaculture is economically mainly affected by marine litter due to fouled propellers. The average costs to the aquaculture industry is estimated at € 155,549 per year.

Harbours and marinas
In the UK, port and harbour industries spend approximately € 2.4 million on a yearly basis, removing litter with an average cost of € 8,034 per harbour. However, costs for individual harbours can be as high as € 38,538 per year.

Rescue services
Rescue services are affected by marine litter in terms of navigation, fouled propellers and blocked intake pipes. Rescues to vessels with fouled propellers cost between € 830,000-€ 2,189,000.

Agriculture (Shetlands)
Economic costs of marine litter are incurred mainly through damage to property and machinery, harm to livestock and the cost of the removal of litter. In the Shetlands, the agricultural sector suffers a total loss of € 252,331 per year, with an average cost of € 841 per crofter.

Power stations, seawater abstractors and water authorities

Impacts of marine litter on these industries are mainly related to blockage of cooling water intake screens and additional maintenance costs. Since these data are not well recorded, estimates on these costs are difficult to determine.

A.11 Litter in harbours

Harbours collect litter from ships as well as clean up floating debris from the harbour itself. Based upon the European Directive for the Port Reception Facilities (PRF), as of 2004, all ships which dock in Dutch harbours are required to dispose of their wastes at a PRF.
This satisfies the agreements made during the OSPAR treaties. There are different kinds of PRFs. There are wharves and terminals which collect wastes and there are mobile collection facilities, there are also businesses which specialise in the collection and processing of waste products. Garbage collection points in harbours play an important role in limiting the amount of litter and debris in the marine environment.

Table A.5 Data on waste from ships in the harbour of Rotterdam (Rotterdam Havenplan, 2010)

jaar	2004	2005	2006	2007	2008
Aantal bezoekende zeeschepen Havenregio R-R	34.831	34.954	35.990	37.095	36.780
aantal afgiften annex I (scheepsafval)	1.351	4.756	2.530	3.368	4.756
totaal hoeveelheid afgegeven scheepsafval (m^3)	34.749	41.756	42.417	54.640	61.567
gemiddeld afgegeven hoeveelheid scheepsafval (m^3/afgever)	26	9	17	16	13
aantal afgiften annex IV	19	37	46	61	39
totaal hoeveelheid afgegeven annex IV (m^3)	703	4.294	2.878	4.760	2.244
gemiddeld afgegeven hoeveelheid annex IV(m^3/afgever)	37,0	116	63	78	58
aantal afgiften annex V (scheepsafval)	4.398	15.462	22.026	29.646	34.346
totaal hoeveelheid afgegeven annex V (m^3)	19.923	28.584	21.745	33.873	35.826
gemiddelde afgegeven hoeveelheid annex V(m^3/afgever)	5	2	1	1	1

Table A.5… demonstrates that the total amount of shipping garbage in the harbour of Rotterdam has increased from 34.749 m^3 in 2004 to 61.567 m^3 in 2008. Focusing on annex V (food, domestic and operational waste, etc.) an upward trend can also be observed, even though the average amount handed in per ship has decreased.

These data include ships that sail across the world, and therefore do not represent the amount of litter in the North Sea, however, it does give an indication of the amount of waste produced that would otherwise end up in the marine environment. Schatting over hoeveel % van afval daadwerkelijk wordt ingeleverd? Dan kunnen we een uitspraak doen over hoeveel er aan afval in zee terecht zou komen vanaf schepen?

B Comparison of litter in rivers in other countries

B.1 Introduction

In this appendix, a comparison is made between litter in rivers in the Netherlands, Singapore and Korea. The main results are presented in table C1.

Table C1 Main result of the comparison

	Fine (€)	**Enforcement**	**Organisation**	**Amount of litter in the riverine system (m^3)**	**Money spent to clean up and prevent litter (€)**
Netherlands	60-120	+/-	Nederland Schoon, Milieu Centraal	1000	250 million
Singapore	190	++	National Environment Agency, Waterways Watch	unknown	19 million
Korea	unknown	unknown	unknown	32,000-175,000 (on 16 different locations combined)	unknown

Netherlands

Dutch citizens pay hundreds of euro's every year for the municipalities to collect and incinerate their household garbage. Littering in the Netherlands officially results in a fine of approximately 100 euro's (Wikipedia), however, enforcement is often missing.

Raising awareness on litter in the Netherlands is mainly done by NGO's such as 'Nederland Schoon' and 'Milieu Centraal', who have campaigns on preventing litter from entering the environment.

incinerate their household garbage. Littering in the Netherlands officially results in a fine of approximately 100 euro's (Wikipedia), however, enforcement is often missing.

Raising awareness on litter in the Netherlands is mainly done by NGO's such as 'Nederland Schoon' and 'Milieu Centraal', who have campaigns on preventing litter from entering the environment.

As demonstrated in this report, numbers on the amount of litter in the riverine environment are difficult to come by, but seem to be in the order of 1000 m^3 per year for the Meuse. Estimates on the total amount of litter in the Netherlands range from 50 million to 300 million kg/year (http://www.milieucentraal.nl/themas/afval-heb-je-zelf-in-de-hand/zwerfafval). A study by Deloitte concluded that the prevention and collection of litter in the Netherlands costs approximately €250 million http://www.hetccv.nl/binaries/content/assets/ccv/instrumenten/overlast-en-verloedering/kostenonderzoek_zwerfafval_deloitte.pdf).

B.2 Singapore

In Singapore, strict laws on littering are in place with fines for first offenders amounting to 300 S$ (approximately € 190). These are issued even for small litter items such as sweet wrappers or bus tickets.

The National Environment Agency is the governmental body responsible for raising awareness for littering, and have set up the 'Litter-free Campaign' (Website National Environment Agency). Organisations of volunteers, such as 'Waterways Watch' are also active in Singapore, monitoring, restoring and protecting the aesthetics of the waterways. They focus on six rivers and canals, including the Singapore and Kallang River, as well as the Pelton and Rochor Canal.

According to the National Environment Agency of Singapore, 30 million S$ are spent annually to clean up litter, which amounts to approximately 19 million € (http://www.nea.gov.sg/ar07/homeward-litter.html). In total around 7000 people ('litter bugs') were caught littering in the year 2006. The management area and the total length of these rivers are smaller than the area of the Netherlands and the total length of the Dutch main rivers. Furthermore the river system is clean compared to the river system in the Netherlands. This comparison might indicate that the Netherlands can save on the budget for cleaning and processing waste. This requires a much more in depth elaboration.

B.3 Korea

A summary of governance aspects of litter in rivers and coastal areas in Korea was presented in Marine Pollution Bulletin 60 (2010):

The ''National Basic Plan for the Marine Debris Management" was institutionalized in 2008 by most of the relative central government entities (MLTM, 2008). It differs from marine debris regulation in other countries in that the central government has delegated much of their authority in this matter to local governments, government-controlled organizations, research institutes, and nongovernmental organizations. Representatives executing Korea's policy on the marine debris initiatives include (1) underwater marine debris removal programs including those in ports and harbours, since 1999 (Kang et al., 1999; Hwang and Ko, 2007), (2) development of a practical integrated system for marine debris in 1999 (MOMAF project report, 1999–2007, MLTM project report, 2008–2009), (3) river basin marine debris management systems since 2001 (Nam and Jung, 2005; Ha et al., 2006), (4) a fishing gear buy-back program since 2003 (Jung et al., 2006; Cho, 2009, UNEP, 2009), and (5) a national coastal monitoring and education system on marine debris since 2000 (MOMAF project report, 2001–2007).

Key data on the litter problem in rivers and coastal zones give an impression of the size of that problem in Korea (Marine Pollution Bulletin 60, 2010).: Marine debris discharge from Korea has been increasing steadily since the 1970s, concomitant with the industrialization and urbanization of coastal areas. Moreover, about 64% of the population lives near rivers and coastline. As the population increases, vast quantities of marine debris are generated from both land and aquaculture, which are dense in coastal areas. The Ministry Land, Transport and Maritime Affairs (MLTM) (formerly the Ministry of Maritime Affairs and

Fisheries, or MOMAF) estimates that a total of 159,800 tons (units: metric tons if it is not specified) (109,400 tons from land-based and 50,400 tons from ocean-based activity, with accumulation mainly on the seabed) of marine debris are generated each year in Korea (MLTM, 2008).

In 16 different locations nets have been placed to collect the riverine litter. The cumulative amount of debris is presented in figure 3.3 for a river in Korea. An example is presented in figure 3.4 of the collection and the removal of floating debris with a net across a river.

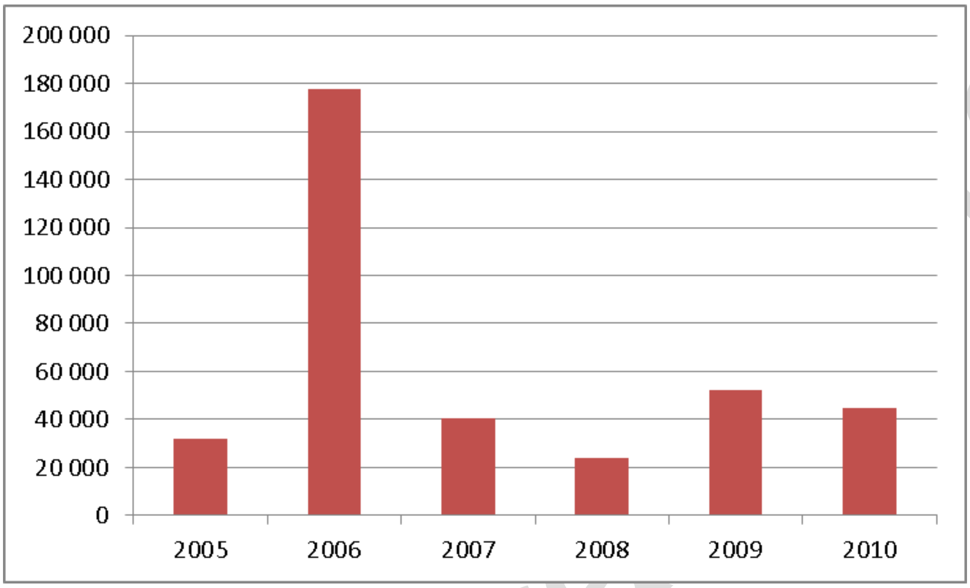


Figure 3.3: Data on the amount of debris (in m3) caught in a net in Korea from 2005-2010 on 16 different locations.

Data from 2005 – 2010 illustrate the variation in volumes of removed floating litter in 16 locations in rivers mostly lakes upstream of barrages with total amounts ranging from 24,000 m3 in 2008 to 180,000 m3 in 2006 per year probably depending on the yearly floods. The yearly cost involved vary also with a maximum of about Euro 4 million in 2006. The average cost for removal of debris is around Euro 25 per m3. However, it is uncertain if in this average rate are included also the cost for transportation and processing.

The plastic pollution and the amount of floating debris in Korean rivers need even more attention than in the Netherlands. Over 60% of the floating marine debris around coastal areas can be traced to land-based discharges (Incheon City Report, 2001).The examples of Korea and Singapore are mentioned here because both countries are highly developed societies and Singapore has made large progress in keeping their rivers clean and in Korea large interventions to collect and to remove floating debris are common. The Netherlands can profit for the development of their policies from the experiences in other countries.

Figure 3.4 Example of litter caught in a net in a Korean river

Figure 3.5 Example of a developed containment boom for floating debris in rivers (Hwang en Ko, 2007)

Indonesia
The Indonesian government also has strict laws on littering. An Indonesian news item reported that in October 2012, 40 people were put on trial for littering or illegally dumping their household waste (http://balirecycling.com/denpasar-trash-trials-catching-fining-litter-bugs/) . Fines ranged from Rp 15.000 to Rp 200.000 (€1.20 to approximately €15). Considering the low living standard in Indonesia, these fines are considerable.

The Sentiong River in Jakarta, with the nickname ‘River of Litter’ is famous for its garbage. One of the main problems with such amounts of litter is that the river drainage is blocked, and floods occur more frequently.

C Cost of removal floating debris Meuse valley in Limburg

Rijkswaterstaat Limburg spent on average Euro 850.000,- yearly on the collection, transportation and storage of debris and litter). They commissioned these activities to contractors. Therefore Rijkswaterstaat has no detailed information about the amount of collected litter and debris. The same holds for the waterboards.
Rijkswaterstaat Limburg is responsible for the Meuse from kilometre number 2 to kilometre number 172, a stretch with a total length of 170 km. This means an average cost of Euro 5.000,- per kilometer per year. After the extreme flood in 1994 they spent a total budget of about euro 15,000,000 (..?). This corresponds to about Euro 8,800 per kilometre along the river.

The Waterboard Roer en Overmaas spent in 2004 only Euro 4,000.- but in 2006 the costs were much higher, see table C.1.:

Table C.1 Costs for removal of litter by Waterboard Roer en Overmaas in 2006

Item	**Costs (Euro's)**
Dumped waste and debris	10,000.-
Litter	50,000.- (100.000 by Waltje, 2007)
Litter removed by contractors	15.000,- (Waltje, 2007)
Total	80.000,-

That water board estimated that on average euro 150.000 is spent yearly on removal and collection of litter in their management area (Steegemans, Water board Roer en Overmaas, 2008). Their hilly management area is about 92,000 hectare and this means an average cost of 0.05 to maximum 1.6 Euro/hectare. Their cost for removal of litter and debris varies strongly from year to year and maybe these costs are related to the maximum discharge in the River Meuse(or the rainfall in their management area), see Table A.1 and Figure A.2. For several waterboards the average yearly cost for removal of debris and litter are estimated at 1 to 2 euro/ hectare.(Deloitte, 2010). The cost mentioned by Roer en Overmaas fit in this range.

In 1994 the maximum cost spent by the water board is estimated at Euro 150.000 after a flood with a maximum discharge of about 3,039 m^3/s. That was an extreme flood with an estimated return period of 1 in 150 years.

The floods in autumn 2010 and winter 2011 had maximum discharges of 1,600 and 2,200 m^3/s. In that period in total 2,500 ton (about 2,500 m^3 and about 10 % plastic litter 250 m^3) debris and waste had been collected by contractors along the Meuse from kilometre 2 to 146 barrier Sambeek and about 14 kilometer Roer Rivers in province Limburg (archive of water board Peel en Maasvallei). This collection of waste was a joint action by Rijkswaterstaat, two local water boards and several local municipalities and it costed about Euro 430,000 in total (on average Euro 170 per ton waste, on average 2,750 euro/kilometre river). In addition waste and litter was collected in several actions by volunteers.

Table C.1 Data on cost of removal of litter and debris by Water Board Roer en Overmaas.

Year	**Max discharge Borgharen dorp**	**Cost removal of debris and litter Roer en Overmaas**	**Cost of removal of debris and liter RWS Limburg**
	m^3/s	Euro	Euro
1994	3,040	150,000	About 15,000,000
2004	1,220/1,082	4,000	No data
2006	1,100	80,000	No data
2010	1,025	No data	No data
2011	1,600 and 2,214	40,000 to 60,000	370,000 to 390,000

The relationship between cost for removal of litter and debris and the maximum flood discharge is presented in figure C.2.

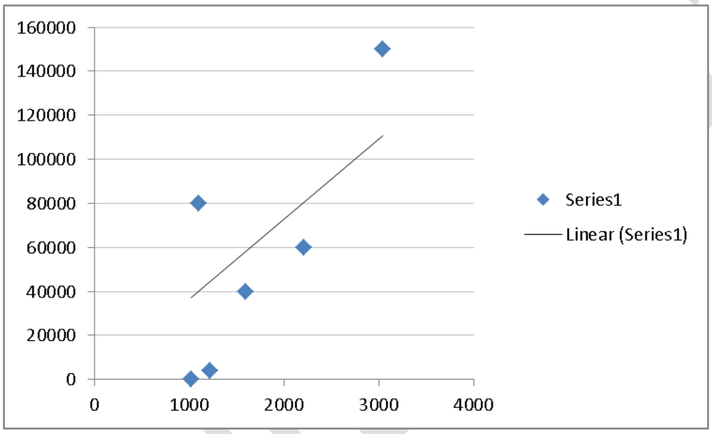


Figure C.2 Tentative relationship between costs for removal of debris and litter for the water board Roer en Overmaas and the maximum discharge in a flood wave

The costs of the waterboards and Rijkswaterstaat for cleaning up their management area from litter is estimated at euro 10 million yearly. In comparison the costs of removal of litter in municipalites cost in total euro 35 million for the placement and maintenance of bins and containers for litter and this figure corresponds to 1 to 4 euro /inhabitant (Deloitte, 2010), see also figure C.3. The cost for cleaning waterways in the Netherlands seem to be reasonable in comparison to the costs for cleaning cities from litter.

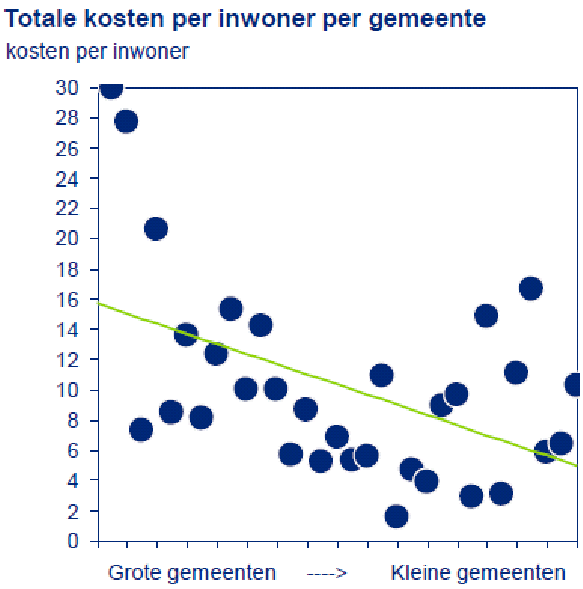


Figure C.3 Cost per inhabitant for the removal of litter in municipalities (Deloitte, 2010)

The removal of litter is most economic for a municipality of average size. To be economic the removal from litter from a certain area all land owners should cooperate and start joint actions, see figure C.4.

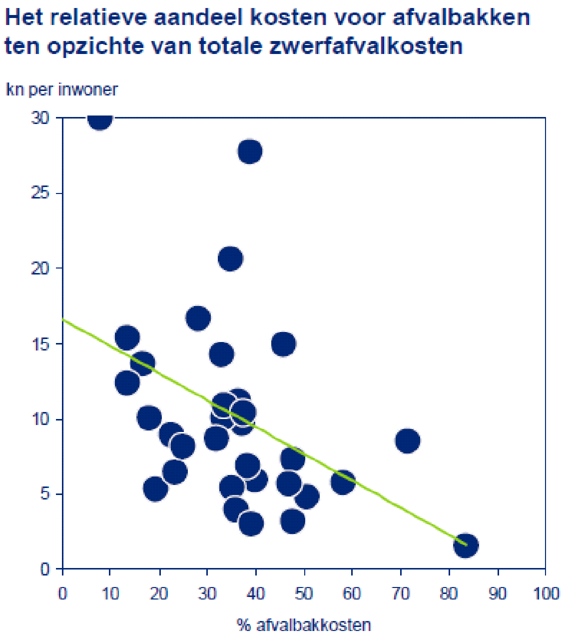


Figure C.4 The costs of bins and containers for litter per inhabitant and as percentage of the total costs.

In general the costs for removal of litter decreases as a municipality spent more budget on litter bins and litter containers.

References

Deloitte Touche Tohmatsu (2010) Kostenonderzoek zwerfafval Nederland.

D Collected debris in the Meuse River

D.1 Introduction

In this appendix most data was retrieved on the internet about actions to remove floating debris from river banks and floodplains of the Meuse catchment. This data collection is probably not complete because of time constraints also the reliability of these data was not investigated in detail. This means that the resulting tendencies include some uncertainty

D.2 Clean-ups

The information of each clean-up is described separately and each clean-up is identified by an arbitrary number.

D.2.1 Clean up 1

As part of a countrywide day for cleaning the environment (landelijke opschoondag) Saturday 12 March 2011 two different organizations Natuurmonumenten and Rijkswaterstaat mobilized about 300 volunteers to clean the southern bank of the River Meusefrom Ravenstein to Waalwijk over a total distance of 75 km along both banks. They collected 600 plastic bags with an estimated volume of 0.015 * 600 = 9 m^3 and 10 containers for large pieces of debris. The total volume of collected debris is estimated at 20 tot 25 m^3 and this volume might contain 2 to 5 m^3 plastic items. This means that debris was removed with a volume of on average 0.003 to 0.007 m^3/100 m river bank after a flood with a maximum discharge at Borgharen of 2,200 m^3/s, see the website Maas schoon? Doen gewoon!.

D.2.2 Clean up 2

Foundation ARK together with the foundation Reinwater, Rijkswaterstaat, the Waterboard Roer en Overmaas and Belgium Riviercontract Vesdre organize a yearly clean-up of the river bank by school classes. In an annex in the report (Paassen, 2010) detailed data is reported from the collected items by ARK, see table D.1..

Table D.1 Number of items collected from by volunteers in spring 2010 after a flood with a maximum discharge of 1,000 m^3/s.(ARK, 2010)

	Meers	Molenplas	Pietersplas	average
Length of bank	1.5 km	0.5 km	1.5 km	100 m
Total items	2529	2049	1881	258.4
Plastic particles	534	467	104	44.7
Plastic bottles	302	166	398	34.6
Plastic shells	217	284	144	25.8
Plastic bags	125	327	214	26.6
Plastic cups and other forms	146	191	221	22.3
Total plastic items	1324	1435	1081	153

The conclusion is that 150 to 200 plastic items per 100 m bank can be found on severely polluted banks along the Meuse River. However, the volume of this pollution is not known.

Combining both results from actions to collect debris and litter along the River Meuseand assuming a linear relationship between maximum discharge during a flood wave and the plastic items along the bank, results in an average volume of a plastic item of about 0.019 m^3/100m, see Table D2.

Table D.2 Estimation of the volume debris along 100 m bank Meuse river

	Estimated volume of a item (m^3)	**Average Number items (-)**	**Average estimated volume (m^3)**
Length of bank		100 m	
Total items		258.4	
Plastic particles	2 .10-6	44.7	0.0000884
Plastic bottles	700 10-6	34.6	0.0173000
Plastic shells	10.10-6	25.8	0.000258
Plastic bags	20 10-6	26.6	0.0005328
Plastic cups and other forms	50 10-6	22.3	0.001116
Total plastic items		153	About 0.02

D.2.3 Clean up 3

The nature conservation organization Limburgs landschap (2012, jaarverslag 2011)) has collected more than 700 m^3 debris along the Meuse valley from its own areas spring 2011, after a flood wave with a maximum discharge of 2,200 m^3/s distributed along the Meuse as follows: District Zuid 300 m^3, district Midden more than 300 m^3 because of the relatively long bank lines of it properties in that district and district Noord 250 m^3 and in total more than 850 m^3 debris, of which 10 % might be plastic litter, that means a volume of more than 85 m^3 plastic material. If the bank lines of their properties have an assumed total length of 30 km and an assumed pollution of 0.06 m^3/100m than 0.06 * 300 = about 20 m^3 plastic litter along the bank lines and about more than 65 m^3 plastic litter in the floodplain. That is possible if also illegal waste dumping have occurred in their management area.

D.2.4 Clean up 4

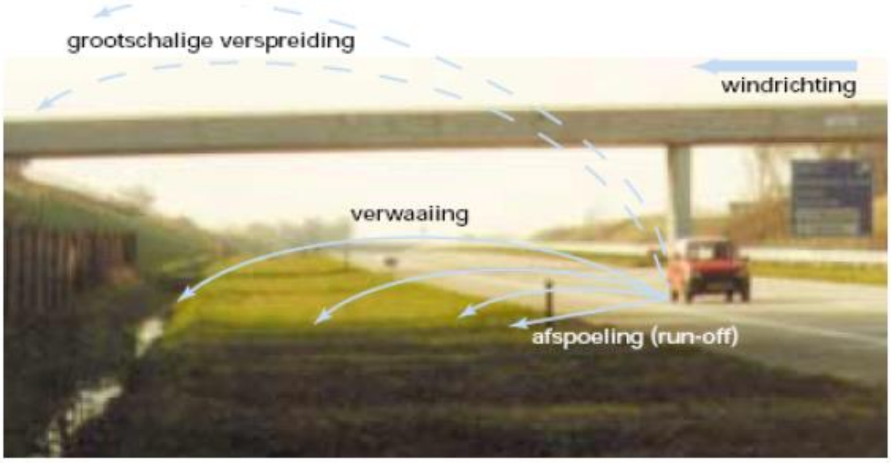
The floods in autumn 2010 and winter 2011 had maximum discharges of 1,600 and 2,200 m^3/s. In that period in total 2,500 ton (about 2,500 m^3 and about 10 % plastic litter 250 m^3) debris and waste had been collected by contractors along the Meuse from kilometre 2 to 146 barrier Sambeek and about 14 kilometer Roer Rivers in province Limburg (archive of water board Peel en Maasvallei).

Assumed 0.06 m3/100 m bankline results in a volume of about 100 m^3 plastic litter along banks (veek edges) and 250 – 100 = 150 m^3 plastic in the floodplain.

D.2.5 Clean up 5

A team of students guided by Tweehuysen collect floating debris at low river discharges (Tweehuysen, 2012). The interesting results show that during periods with low discharge the drain water from road sides discharging straight to the river can contain large numbers plastic pieces after mowing the road side.

Figuur 1: Verontreinigingsroutes vanaf de weg (bron: CIW, 2002)



Er zijn verschillende factoren die mogelijk van invloed zijn op runoff en verwaaiing (Poot, 2009):

1. wegopbouw (aantal rijstroken, aanwezigheid vluchtstrook, aanwezigheid middenberm, aanwezigheid vangrails, aanwezigheid spitsstrook);
2. wegonderhoud (reinigen wegdek, onkruidbestrijding, afschrapen van de berm, maaien van de berm);
3. wegdektype (e.g. ZOAB, DAB, SMA);
4. verkeersintensiteit;
5. neerslaghoeveelheid- en intensiteit;
6. windrichting;
7. ligging van de weg t.o.v. omgeving (i.e. verdiept/ verhoogd, open/ beschut);
8. droogteperiodes ('first-flush' effect).

Figure D.1 Pollution of berms near highways

D.2.6 Clean up 6

In the Biesbosch nature reserve in the most downstream stretch of the River Meusea clean up by volunteers failed because the reed had grown too high in early summer. This is a reason why clean ups with volunteers are organized generally in spring after the winter floods.

D.3 Photographs of debris and plastic litter

Figure D.2 Debris on a bank of the River Meuse near Borgharen, 10 January 2011

Figure D.3 Bank of the River Meusenear Borgharen 10 January 2011 (courtesy Mrs Wolthuis)

Figure D.4 Island in the Meuse River, Smeermaas near Lanaken , March 2011 (artist Toon Eerdekens)

Figure D.5.. Illuminated island full plastic litter during night, Meuse River, Smeermaas near Lanaken, 28 March 2011 (artist Toon Eerdekens)

D.4 Combination of data

The combination of the data of the four cleaning-up actions shows a very preliminary dependency between the plastic pollution of the bank, the floodplain and the maximum discharge during a flood wave, see Table .D.3. It is mentioned that only large plastic items are collected in clean ups and small items are not collected.

Table D.3 Tentative relation between plastic pollution along a bank line, floodplain downstream Maastricht and the maximum discharge during a flood wave

Year		Maximum discharge (m^3/s)	Average plastic pollution of the bankline (m^3/100m)	Average plastic pollution in floodplain (m^3/100m)
2010	Upstream Sambeek	1,600	0.02	Not measured
2011	Downstream Sambeek	2,200	0.003 to 0.007	0
	Upstream Sambeek	2,200	0.06 (assumed)	0.1 to 0.2

Between Liege and Maastricht a closed barrier near Lixhe blocks the passage of litter and as an example upstream of the barrier in total 917 ton litter has been removed from the Meuse in 2007 (according to a proposal by ISI).

The amount of floating debris in the autumn 2010 flood, maximum 1,600 m3/s in front of the lock near Borgharen can be seen in a photograph, see Figure D.1.

Figure D.6 Photo floating debris in front of the lock Borgharen in November 2010.

Figure D.7 Areal view of lock Borgharen with the area of the floating debris indicated by a red line.

In November 2010 the maximum discharge in the River Meusewas above 1,600 m^3/s. The amount of floating debris had been estimated form figures B.1. and B.2. The length is about 40 m, the width is about 60 m and the thickness is estimated at 0.3 m. The volume of floating debris is about 720 m^3. Assuming that 20 % has been composed of plastic material the volume of plastic waste is 150 m^3.

The upstream bifurcation has a total width of 175 m and assuming that the line of floats is in use all debris was accumulated in front of the lock.

In the eighties of last century unexpected summerfloods caused havoc at campingsites along the Meuse River. Caravans and pieces of caravans could be seen floating fast in the river and breaking up in pieces after hitting hard points as bridge piers.

D.5 Summary of the plastic litter after a flood wave of 2200 3/s

In the stretch Maastricht – Roermond on average 0.057 m^3 plastic litter per 100 m bank after a flood with a maximum discharge of 2,200 m^3/s. So 64 km (kmraai 79 – kmraai 15) means a total 36 m^3 plastic if it is assumed that debris accumulates only at one bank and not at both at the same rate. And over a distance of an estimated 20 km bank 11 m^3 of this waste material was collected and removed from the river system.

In the stretch Ravenstein – Waalwijk on average 0.0065 to 0.008 m^3 plastic litter per 100 m bank after a flood with a maximum discharge 2.200 m^3/s.This distance is about kmraai 236 – kmraai 182 = 54 km so about 2 to 5 m^3 plastic material was collected in total.

This indicates that the amount of plastic litter reduces strongly in downstream direction along the Meuse River: This confirmed by Paassen (2010) who mentions that downstream of sluice Sambeek the amount of floating debris is small.

Extrapolation downstream of Sambeek = kmraai 248 – kmraai 147 = 101 km = 8 m^3 plastic litter along the banks, this means roughly 10 m^3 plastic and upstream of Sambeek kmraai 146 – kmraai 2 = 144 km is about 80 m^3 plastic litter along the banks. In total about 80 + 10 = about 100 m^3 plastic litter along the banks of the River Meuseafter a flood wave with a maximum discharge 2,200 m^3/s.

A preliminary estimate of a mass balance of plastic litter in the stretch Maastricht – Sambeek, 132 km distance after a flood with a maximum discharge of 2,200 m^3/s and based on a incomplete data set:

<u>Inflow</u>

from upstream of Maastricht	100 m^3 plastic litter
from other sources as recreation/agriculture/ industries/dumping in Maastricht – Sambeek	125 m^3 plastic litter
total inflow	275 m^3 plastic litter

<u>outflow</u>

collection by contractors from floodplain and natural degradation	240 m^3 plastic litter
collection by volunteers from bank line	25 m^3 plastic litter
downstream outflow	10 m^3 plastic litter
total outflow	275 m^3 plastic litter

The mass balance of the Dutch part of the River Meuseof only floating plastic litter (not including foils and high density plastics and plastics sunk by fouling after a flood with a maximum discharge of 2,200 m^3/s: inflow = outflow if it is assumed that the storage of plastic litter in the considered stretch did not change in the period before and after the flood:
275 m^3 = 275 m^3

D.6 Preliminary conclusions:

- Data on plastic litter in the River Meuseis scarce. From photographs it is estimated that 10 to 20 % of floating debris is plastic material.
- Data on amounts of floating debris is not available in a systematic way and it is fragmented.
- The volume floating plastic litter reduces strongly from the border with Belgium to the Dutch Biesbosch, during a flood with a maximum discharge of 2,200 m^3/s from 100 m^3 to the magnitude of 10 m^3.

D.7 Literature

Rijkswaterstaat (November 2012), Afstromend wegwater, kader
Penning de Vries, L en J.W. Berendsen (RHDHV)