Potential risk of microplastics in the fresh water environment

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It all started with the discovery of high concentrations of plastic litter ("plastic soup") in the northern path of the Pacific Ocean late nineties (see e.g. Moore et. al., 2001) and recently caused a lot of commotion around the group of microplastics, which may eventually end up in the marine food chain via sewage treatment plants and riverine transport. After the endocrine receptors, medicines and nanoparticles, microplastics seem to be the next group in line water managers are confronted with. Because of the raised commotion associated with this new group of emerging compounds, water managers have lots of questions about the risks and sources of this group of compounds and the possible consequences for them in terms of emission prevention and water treatment. In this paper the latest developments regarding microplastics in the aquatic environment are described, including an inventory of the most important knowledge gaps.

How are microplastics defined, and what are they used for?

According to international agreements, microplastics are pieces of plastic smaller than 5 millimetres (Arthur et. al., 2009). A lower limit has not been set, which makes it impossible to see the smaller particles in this category by the naked eye. Microplastics can be divided in primary and secondary microplastics. Secondary microplastics are plastic particles, originating from fragmentation of larger plastics fragments under the influence of UV radiation, oxidative properties of the atmosphere and hydrolytic properties of the aquatic environment. This wearing may occur when the plastic is actually used or in the waste phase.

Primary microplastics are produced as such, and may have different applications. An important application is the use of preproduction pellets as a precursor for the production of new plastic products. During transport these pellets may end up in the environment (Doyle et. al., 2011). Another popular application is the use of plastic particles in Personal Care Products like scrubs, but also in cleaning agents and all kinds of industrial applications. It is expected that plastic nanoparticles (<100 nm) will be used more and more in the production of electronic devices, cars, airplanes and medicines.

The ratio between primary en secondary microplastics in the environment is not known, although primary microplastics are supposed to be less common than secondary particles (Barnes et. al. 2009). Unfortunately, the difference cannot be made in an analytical manner. Preproduction pellets en synthetic fibres (almost always secondary microplastics) however are well recognisable.

In the next paragraph the different applications of microplastics will be described, with a focus on the use of micro beads in Personal Care Products and synthetic fibres used in textile. As these sources mostly consist of consumer products the microplastics, originating from these applications, will end up in the aquatic environment only after passing a sewage treatment plant (STP). Therefore, the removal efficiency of microplastics in the STP is a crucial step in the final emission of these particles.
The addition of microbeads to Personal Care Products as toothpaste, scrubs and shower gels has gained a lot of attention recently. The chemical concerned is mostly polyethylene (PE), although also polypropylene (PP), polyethylene terephthalate (PET), poly methyl methacrylate (PMMA) en Teflon (PTFE) can be found. Microplastics in these products are so popular because of their polishing and emulsifying effect. Besides, their properties (density, colour, roughness) can be easily adjusted to the product of concern. They have been used already for years in these products (Gregory, 1996), but the concern about these products has been scientifically recognised only in 2004 by Richard Thompson. In a paper by his hand in Science, he reported the presence of microplastics on beaches and the water column in the North Sea (Thompson et. al., 2004). Last years the number of scientific papers concerning environmental risks of microplastics has increased substantially, an overview can be found in Leslie et. al. (2011). Little is known about the amount of microplastics used in Personal Care Products and the amount eventually ending up in the aquatic environment. According to a recent study, the estimated amount of polyethylene as microplastics is on average 2.4 mg per person/day, as a result of the use of microplastics in fluid soap (Gouin et. al., 2011). Extrapolating this study to the Dutch situation, based on a population of 6,5 million in the Rhine catchment en 3,5 million in het Meuse catchment, results in an emission van 15,6 kg/day for the Rhine en 8,4 kg/day in the Meuse catchment.

A second source of microplastics in the aquatic environment is synthetic textile. The use of plastic material (nylon, polyester, acryl, etc.) in clothes, like fleece keeps increasing. This plastic may concern recycled material, but doesn't have to be. One study has shown that one single piece of garment may produce up to 1900 plastic fibres per wash (Browne et. al., 2011). There are no more detailed estimates of these emissions at the moment, as detailed information is lacking.

Microplastics are also used in the process of sand-blasting of all kinds of objects. The larger part of these particles is recycled again. However, substantial losses may occur, resulting in emission to the aquatic environment. The total amount of microplastics used by this application is lower than by the first two. However, the direct emission to the aquatic environment may be substantial. The same holds for scrubs and cleaning agents used in inland and recreational shipping. These plastic particles will end up directly in the surface water, without passing an STP.

Next to the above mentioned applications, emissions of microplastics may also occur as a result of run-off of rainwater from roads, parks and farmland, the use of compost or sewage sludge on farmland, wearing of tyres, particles of construction materials or shoes, transported with rainwater, which may end up indirect via the STP, or directly in the surface water.

About the presence of ultrafine plastic fragments (< 1 micrometre) en nanoplastics (1-100 nm) in the aquatic environment we don't know anything at the moment. In principle all plastic will degrade into small fragments in the course of time and the possible environmental risks of these secondary nano-sized plastic particles will get more attention in the coming years. Besides, the use of nanoplastics will probably increase the coming years as applications in electronic devices, cars, airplanes and medicines will increase.

Environmental contamination of microplastics originating from Personal Care Products has drawn a lot of attention recently. Therefore a number of retail chains in the Netherlands have decided to stop the sale of Personal Care Products containing microplastics. Besides, an important producer of Personal Care Products has decided in 2012 to stop adding microplastics to its products in 2013 in the Netherlands and worldwide in 2015.

Two resolutions from the Dutch Parliament[1,2] has led to a proposal of the Dutch Ministry of Infrastructure and Environment to ban the use of microplastics in Personal Care Products. At the moment, the same ministry is leading a dialogue with the cosmetics industry with the purpose of voluntary removing microplastics from these products. These initiatives will probably lead to a diminished inflow of microplastics into the aquatic environment.

[1] https://zoek.officielebekendmakingen.nl/kv-tk-2012Z18380.html

[2] http://www.rijksoverheid.nl/documenten-en-publicaties/kamerstukken/2011/11/07/beantwoording-kamervragen-watervervuiling-door-microplastics-in-consumentenproducten.html

The role of STPs in removal of microplastics

At the moment little is known about the removal efficiency of microplastics in an STP. Because of the low density a substantial part of the plastic particles will remain floating on the water surface microplastics. Sedimentation tanks are not designed to remove light particles as polyethylene and nylon, whenever these particles are not captured in the flakes produced by the activated sludge or will end up in de drift layer. Also in the primary settlement these particles will not be removed, and for the time being they are also not intentional removed by the addition of flocculants en coagulants. A pilot study performed by the Vrije Universiteit in cooperation with the TU Delft en Deltares showed that approximately 90% of the plastic particles present in the influent were removed in the STP, finally resulting in 20 particles per litre effluent (Leslie et. al., 2012). These measurements were done during rainwater discharge in the morning peak, and therefore only indicative. Moreover, recent German research shows a similar number of particles in effluent (Dubaish & Liebezeit, 2013). This would mean that, based on approximately $2*10^9$ m^3 sewage in 2010, 100 million particles would end up in the Dutch surface water. However, too little is known about this relative new subject to validate this number. When more information becomes available about the removal efficiency of microplastics in STPs under different circumstances, we can estimate more accurate the real contribution of microplastic emission by STPs and select the best technology available for removal of microplastics.

The 90% of the microplastics that is removed in the STP eventually ends up in the sludge. High concentrations of microplastics have already been found in marine dumping sites of sludge in Great Britain (Browne et. al., 2011). In the Netherlands most of the sludge is incinerated, direct or indirect via fermentation or composting of the sludge, thereby removing microplastics from the environment definitive. However, in surrounding countries, sludge is still often used as fertilizer or soil amendment. Via runoff these microplastics may also end up in the aquatic environment.

What are the environmental risks of microplastics?

The plastic particles that eventually end up in the surface water are not easily biodegradable under normal environmental conditions. The degradation rate of synthetic polymers are extremely low (depending on the type of plastic and environmental conditions probably ranging from a few decades to several centuries), resulting in an accumulation of microplastics in the aquatic environment for the time coming. The risk of microplastics is primarily caused by the combination of persistency of these materials and the potential accumulation in food chains.

The desk study performed by Deltares and IVM shows that both humans and animals are capable of taking up microplastics in their body tissues and/or fluids, causing adverse health effects (particle-toxicity). In marine organisms like lugworms, barnacles, mussels, lobsters, petrels and seals microplastics have already been reported. A pilot study from the US showed that nanoplastics have a negative impact on the photosynthetic capability van green algae (Bhattacharya et. al, 2011). Besides, ultrafine particles can be taken up in the intestine of humans. Subsequently these particles can end up in the lymph, heart and vascular system. These particles may cause local inflammations and changes in gene expression, and a cascade of physiological effects. A recent study shows that polystyrene particles up to 240 nm in diameter can be passed on from van mother to child via de placenta (Wick et. al., 2010).

As larger litter, microplastics form a potential source for the introduction of chemical contaminants invasive species and pathogens. The role of plastic litter as a transport vector in fresh water environment is not clear yet.

Finally the presence of microplastics in the aquatic environment may cause additional risks, as chemical compounds added to the to improve its properties (additives), may leach out of the plastic into the environment (Teuten et. al., 2011). Also other chemical contaminants may bind to the microplastics. As organisms may take up the microplastics, a potential risk may be created for both the environment and human health, via consumption of fish and/or shellfish and crustaceans (Leslie et. al., 2011).

Latest developments in policy and research

The adverse effects on the freshwater environment will be comparable with those in the marine environment. In recent years more attention has been drawn to the environmental risks in the fresh water environment, as part of the problem originates from applications and sources. The available information concerning the origin and emissions of microplastics in the fresh water environment however is very scarce. Besides, the available information mostly originates from pilot studies, and therefore fragmented. Therefore, a large need exist for international standardised monitoring studies (see also Hidalgo-Ruz et. al., 2012). Placing of this group of chemicals on the so-called 'Watch List' from the European Water Framework Directive (WFD) would lead to pan-European monitoring in aquatic environments. Also within the international riverine commissions from the Meuse and the Rhine there is growing attention for the issue of microplastics. Also the Dutch government, through the ministry of Infrastructure and the Environment, recognises the issue of microplastics in Dutch surface waters, (see PBL, 2012). In the meanwhile, Deltares has recently executed a desk study about the nature and extent of litter in riverine systems, including microplastics for the same ministry. (van der Wal et.al., 2013). Finally a number of European studies has been started recently (CLEANSEA, MICRO), that will contribute to knowledge about microplastics in the marine environment. Deltares and the Institute of Environmental Studies participate in both.

At the moment there is no specific policy formulated to prevent pollution of surface water with microplastics. Within the Water Framework Directive, microplastics don't play a role at all. Only in descriptor 10 called "Marine Litter" within the Marine Strategy Framework Directive (MSFD) microplastics could be incorporated. At the moment indicators and monitoring programs are being developed for this descriptor (see the EU projects CLEANSEA en MICRO). The Netherlands fulfil a prominent role in the development of international policy on the issue of microplastics. Regional water managers are advised to follow and to connect to the (inter)national initiatives as much as possible. Furthermore, the lack on (inter)national regulation should not withhold regional water managers to develop initiatives on this issue. A joint national monitoring program with the purpose of monitoring the nature and extent of microplastics in the fresh water environment would contribute to a further mapping out this new group of emerging compounds and putting this issue more strongly on the agenda.

References

Arthur, C., Baker, J., Bamford, H. (eds.) (2009) Proceedings of the International research workshop on the Occurrence, effects and fate of micro-plastic marine debris , sept. 9-11, 2008. NOAA Technical Memorandum NOS-OR&R-30.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos T Roy Soc B, vol. 364, pp.1985-1998.

Bhattacharya, P., Lin, S., Turner, J.P., Pu, C.K. (2010) Physical adsorption of charged plastic nanoparticles affects algal photosynthesis. Phys Chem C 114, pp. 16556-16561.

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.

Doyle, M.J., W. Watson, N. M. Bowlin, S. B. Sheavly (2011) Plastic particles in coastal pelagic ecosystems of the Northeast Pacific ocean. Mar. Environ. Res., vol. 71, pp. 41-52.

Dubaisch, F., G. Liebezeit (2013) Suspended microplastics and black carbon particles in the Jade syste, Southern North Sea. Water, Air Soil Pollution, vol. 224, pp. 1352-1359.

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, 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.A., 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.A., M.D van der Meulen, F.M. Kleissen 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.

Moore, C.J, S.L Moore, M.K Leecaster, S.B Weisberg (2001) A Comparison of Plastic and Plankton in the North Pacific Central Gyre. Mar. Poll. Bull, vol 41, pp. 1297-1300.

PBL Netherlands Environmental Assessment Agency (2012) Kwaliteit voor later 2. Evaluatie van het waterkwaliteitsbeleid. ISBN: 978-94-91506-25-3. PBL-publicatienummer 500208001.

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., Takada, H. (2009) Transport and release of chemicals from plastics to the environment and to wildlife. Philos T Roy Soc B, vol. 364, pp. 2027-2045.

Thompson, R.C., Olsen, Y., Michell, R.P., Davis, A., Rowland, S.J., John, A.W.C., McGonigle, D., en Russel, A.E. (2004) Lost at Sea: Where is All the Plastic? Science, vol. 304, pp. 888.

Van der Wal, M., D. Vethaak, M. van der Meulen, E. Roex, Y. Wolthuis, G. Tweehuijsen (2013) Plastic litter in the Scheldt, Meuse and Rhine Rivers.Contribution to plastic waste in the North Sea. Deltares rapport 1205955-006.

Wick, P., Malek, A., Manser, P., Meili, D., Maeder-Althaus, X., Diener, L., Diener, P-A., Zisch, A., Krug, H.F., Von Mandach, U., 2010. Barrier capacity of human placenta for nanosized materials. Environ Health Perspect 118, pp.432-436.