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Predicting the flow and transport of plastic debris in open waters

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Introduction

Plastic debris of different sizes, shapes, densities, polymer compositions, and mechanical properties have been observed in the riverine, estuarine and marine environments, worsening the ecological and aesthetic values of the environment (*Derraik*, 2002). Moreover, accumulated plastic waste can be an important contributor to urban flooding (*Honingh*, 2020). Therefore, removal and disposal of plastic debris from the aquatic environment is an urgent issue to be addressed.

For that, it is important to know the trajectories and accumulation zones of plastic waste in order to capture them within the water system before they reach the ocean and to identify accumulation hot-spots. In general, there are three steps in prediction of plastic debris transport using a numerical model i.e. 1. to construct an underlying flow hydrodynamic model, 2. to simulate the material transport associated with the flow and 3. to account for the influence of plastics on the flow. The latter is important particularly for zones of accumulation near structures, such as floating debris carpets.

While most research efforts focused on large-scale plastic accumulation and transport as case studies (*Kubota*, 1994; *Neumann*, 2014), a few studies emphasize local processes of plastic debris, including vertical distribution of plastic particles (*Zaat*, 2020; *Kooi*, 2016), rising and settling velocities (*Chubarenko*, 2016; *Khatmullina*, 2017; *Kuizenga*, 2021) and its wave-induced motion (*Alsina*, 2020). To the author's best knowledge, current models for prediction of plastic debris transport assume a highly simplified geometry of plastic items, while making use of parameterization of the physical processes (*Besseling*, 2017), therefore pointing out the need for further research.

Size and inertial effects

Generally, the underlying hydrodynamic is simulated using Navier-Stokes equations and turbulence closures, however, the simulation of particle trajectory is still a difficult task due to its representation in the numerical model.

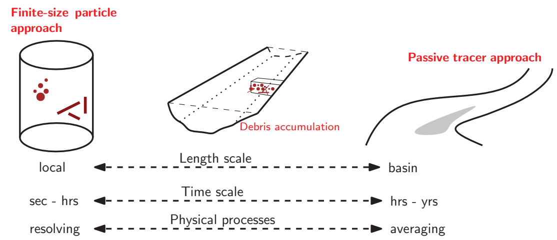

Figure 1: Finite-size particle approach and passive tracer approach currently used for small-scale analysis and large-scale applications, respectively. Simulation of debris accumulation exists halfway of the spectrum.

If the particles are assumed to travel with the flow i.e. negligible inertia, the passive tracer approach is commonly used for particle tracking. However, when inertia and buoyancy become significant, its trajectory should be considered separately from the underlying flow, which leads to a coupling between the particle shape and its net transport (*Dibenedetto*, 2018). This means that in such cases the finite-size particle approach should be applied instead. In this research, the latter approach will be applied for particle kinematic.

Fig 1 summarizes the two approaches and their applicability ranges of length scales, time scales and physical processes. Simulation of debris accumulation at halfway of the spectrum needs to account for not only inertia and buoyancy of plastic items, but also its size and orientation, as explained below.

In the finite-size particle approach, particles smaller than or equal to the Kolmogorov length scale are considered as point-mass, i.e. the so-called point-particle method. However, plastic items larger than this length scale should not be modelled as point particles because of their significantly large size, which otherwise can cause non-physical results (*Loth*, 2009). Hence, a method that accounts for variation of hydrodynamic forces around the plastic item should be applied (*Loth*, 2009), including particle orientation, particle-particle interaction and interactions with banks and structures. In this research,

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since large plastic items will be considered, the concept of "megaplastic" is introduced.

Megaplastic

Based on the apparent physical properties and expected distinct behaviour of some plastic items, the term **megaplastics** is defined for significantly large sizes of plastic debris $>$ 5 cm that are affected by added mass caused by the entrapment of water, air and sediment. These megaplastic also interact with structural components and entangle with other items, a behaviour that may not be observable with smaller macro or micro plastics. It is hypothesized that megaplastic can cause larger-scale physical damages such as flooding, landscape deterioration, while particles smaller than macroplastic (around 5 mm) can induce chemical and biological hazards to ecosystem. It is noted that due to cascading fragmentation, nano-, micro-, and macro-plastic can be seen as later stages of megaplastic degradation.

Future work

Interaction of hydrodynamic and particle dynamic will be studied using numerical simulation and experimental methods. More specifically, more emphasis will be put on plastic debris accumulation at hydraulic structures (e.g. carpet and gate formation at racks), incipient motion, remobilization and settling phenomenon, since these processes also play an important role in waste-removal strategy.

It is believed that this research output will also contribute to a better understanding of the behaviour of smaller items, using improved parameterization of their behaviour in 2D models.

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