Deltares
Enabling Delta Life

The impact of micro-plastics on sediment settling properties

(see also the poster “The interaction between microplastics and suspended particulate matter”)

Session “The impact and transport of microplastics”

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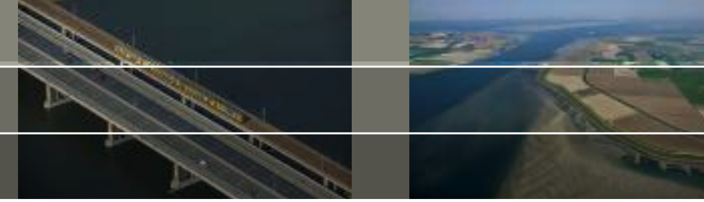
3 April 2019



Background

Microplastics are a course of concern for sediment management in ports. The presence of microplastics (MP's) can increase the sediment volume up to eight per cent (dry weight) for the Rhine estuary [(*)].

The presence MP's might also impact the settling properties of 'normal' sediments. While MP's have a relative low surface charge, the presence of MP's might especially impact the floc formation of sediments in a fresh to salt water gradient[(**)], as is present in many ports.

(*)

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Environment International
Volume 101, April 2017, Pages 133-142
open access

Microplastics en route: Field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota

H.A. Leslie, S.H. Brandsma, M.J.M. van Velzen, A.D. Vethaak

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(**) Bruce R Sutherland · Kai J. Barrett · Murray, K. Gingra, "Clay Settling in Fresh and Salt Water", Environmental Fluid Mechanics, 2014

Clay Settling in Fresh and Salt Water 7

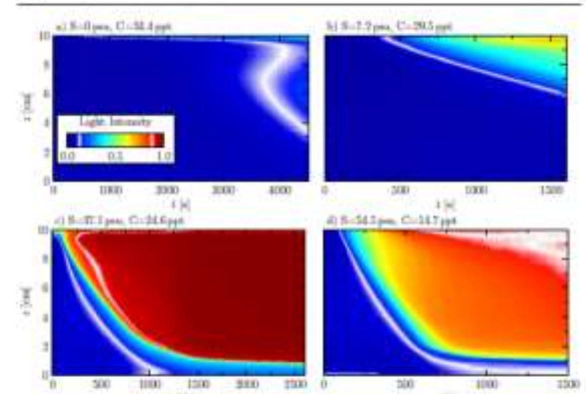

Fig. 3 Vertical time series showing in false-color (inset to (a)) the average intensity of light reaching the camera over time between the bottom and surface of the solution in the tank in four experiments with a) zero salinity, b) low salinity and high clay concentration, c) high salinity and high clay concentration and d) high salinity and low clay concentration. Light intensities near zero indicate high clay concentration whereas high intensities, near one, indicate low clay concentrations. Above each time series are indicated values of salinity (S, in practical salinity units) and clay concentration (C, in parts solute per thousand parts water by mass). All experiments are performed with KW5000 clay.

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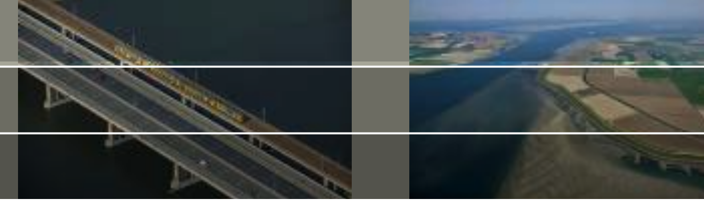

Method

Deltares asked Michiel Blok from the Rotterdam University of Applied Sciences to test if MP's influence the sediment settling rate for Port of Rotterdam harbor sediments.

To test this hypothesis, the follow sediments were sampled:

1. Top layer sediment from the fluid line at a depth of 12 meters (recent 1 sediment),
2. Deeper sediment retrieved from a depth of 13 meters (old 1 sediment), and
3. Deeper sediment retrieved from a depth of 13 meter from a second location) (old 2 sediment).

The hypothesis was that deeper (older) sediment (deposited >10 years ago) have little to no background MP's, while recent sediment already contains MP's.

Figure: Port of R'dam

Figure: Sediment grab sampling

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Method

Spherical polyethylene (PE) MP’s were bought:

- With a size between 10-20 µm, and
- With a size between 63-75 µm

The MP’s were aged by using natural pond water, a stirring machine (set at 500 RPM) and an UV lamp’s for a period of 5 days.

This aged material is called an eco-corona, and it decreases the hydrophobicity of the plastics and increases the density (Galloway, Cole, & Lewis, 2017).

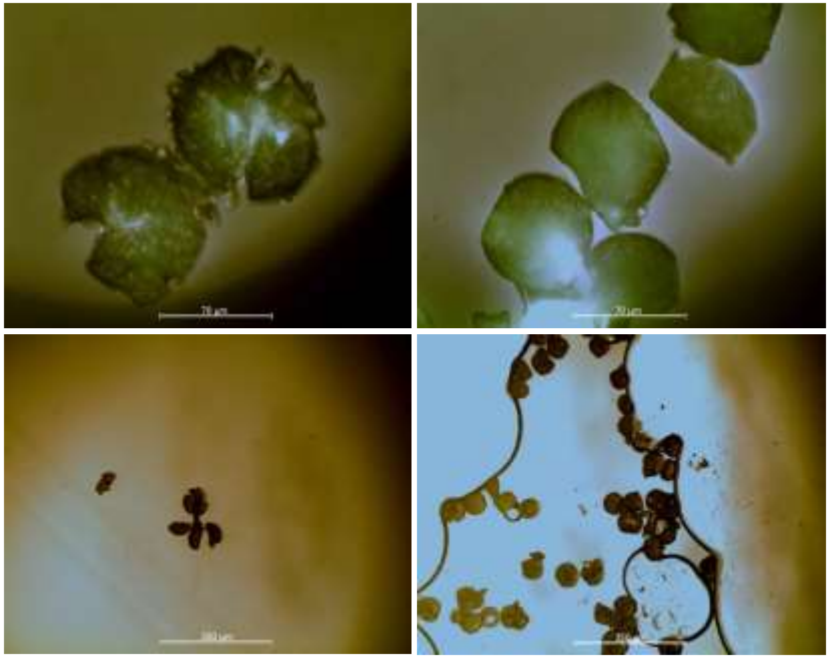

Figure: The difference between aged and non-aged MPs (63-75 µm) under the microscope. The two pictures on the left are aged for 4 days while the two pictures on the right show MPs when taken out of the packaging tubes.

Method

Settling columns were used, with:

- Different types of sediments
- With and without adding MP's
- Different salinity's
- Sheared/unsheared
- In duplo/triplo

The light intensity was measured and compared with a 100% transparent column.

The particle size before and after the settling tests was determined with a static light scattering device (Malvern Mastersizer 2000).

The zeta potential was measured in a concentration range between 0.0045 - 75 mM/L, using both a monovalent salt (NaCl) and a divalent salt ($CaCl_2$).

Figure: Settling columns

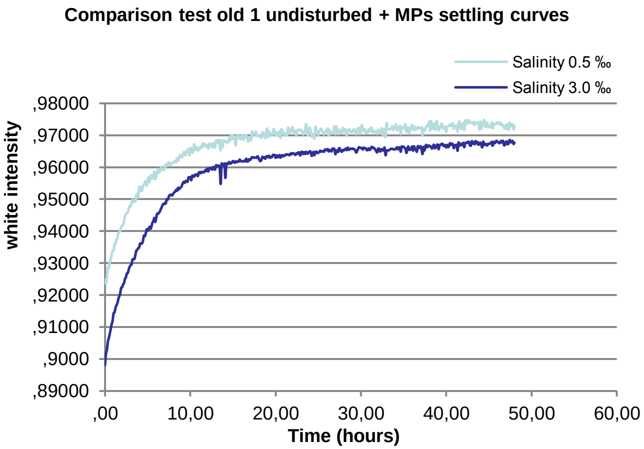

Figure: White intensity in the columns over time, time lap camera

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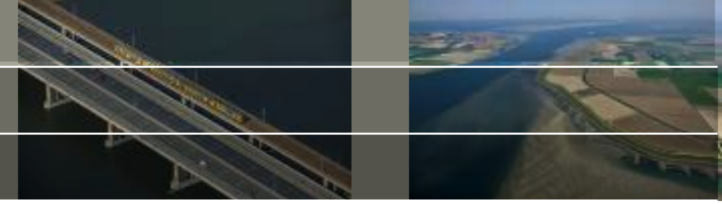
Results and discussion



Settling rates (k’) could be determined based on changes in white intensity (y) over time (t).

Recent 1 Maashaven sample (35 mg/L sediment)		Old 1 Maashaven sample (35 mg/L sediment		Old 2 Maashaven sample (35 mg/L sediment)	
3.0 ‰ of sea salts in Milli-Q water	0.5 ‰ of sea salts in Milli-Q water	3.0 ‰ of sea salts in Milli-Q water	0.5 ‰ of sea salts in Milli-Q water	3.0 ‰ of sea salts in Milli-Q water	0.5 ‰ of sea salts in Milli-Q water
Undisturbed settling	Undisturbed settling	Undisturbed settling	Undisturbed settling	Undisturbed settling	Undisturbed settling
k = 0.1002 (t = 48h)	k = 0.113 (t = 48h)	k = 0.1013 (t = 48h)	k = 0.0891 (t = 48h)	k = 0.1488 (t = 48h)	k = 0.1112 (t = 48h)
k = 0.127 (t = 24h)	k = 0.1313 (t = 24h)	k = 0.1147 (t = 24h)	k = 0.1185 (t = 24h)	k = 0.1647 (t = 24h)	k = 0.1282 (t = 24h)
Disturbed (4 min) settling	Disturbed (4 min) settling	Undisturbed + 3,5 mg/L aged MPs settling	Undisturbed + 3,5 mg/L aged MPs settling	Undisturbed + 3,5 mg/L aged MPs settling	Undisturbed + 3,5 mg/L aged MPs settling
k = 0.1474 (t = 48h)	k = 0.1174 (t = 48h)	k = 0.1888 (t = 48h)	k = 0.181 (t = 48h)	k= 0.3279 (t = 48h)	k = 0.198 (t = 48h)
k = 0.1817 (t = 24h)	k = 0.1668 (t = 24h)	k = 0.2076 (t = 24h)	k = 0.1951 (t = 24h)	k = 0.3587 (t = 24h)	k = 0.2179 (t = 24h)
Disturbed + 3,5 mg/L aged MPs settling	Disturbed + 3,5 mg/L aged MPs settling	Disturbed + 3,5 mg/L aged MPs settling	Disturbed + 3,5 mg/L aged MPs settling	Disturbed + 3,5 mg/L aged MPs settling	Disturbed + 3,5 mg/L aged MPs settling
k = 0.1168 (t = 48h)	k = 0,1108 (t = 48h)	k = 0.0994 (t = 48h)	k = 0.0544 (t = 48h)	k = 0.2533 (t = 48h)	k = 0.2114 (t = 48h)
k = 0.1289 (t = 24h)	k = 0.1383 (t = 24h)	k = 0.1364 (t = 24h)	k = 0.121 (t = 24h)	k = 0.3146 (t = 24h)	k = 0.2518 (t = 24h)

$$y = A * e^{-kt} + b$$

Y = White intensity derived from the photos
A = The total of all colours
k = Sedimentation constant
t = Time (hours)
b = Value for the background colour which takes into account all types of matter which are not SPM or MPs (such as acids)

Most old sediments showed an increased settling rate (up to 2 times higher) when adding MP’s.

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Results and discussion

Changes in the particle size distribution due to MP's are not evident.

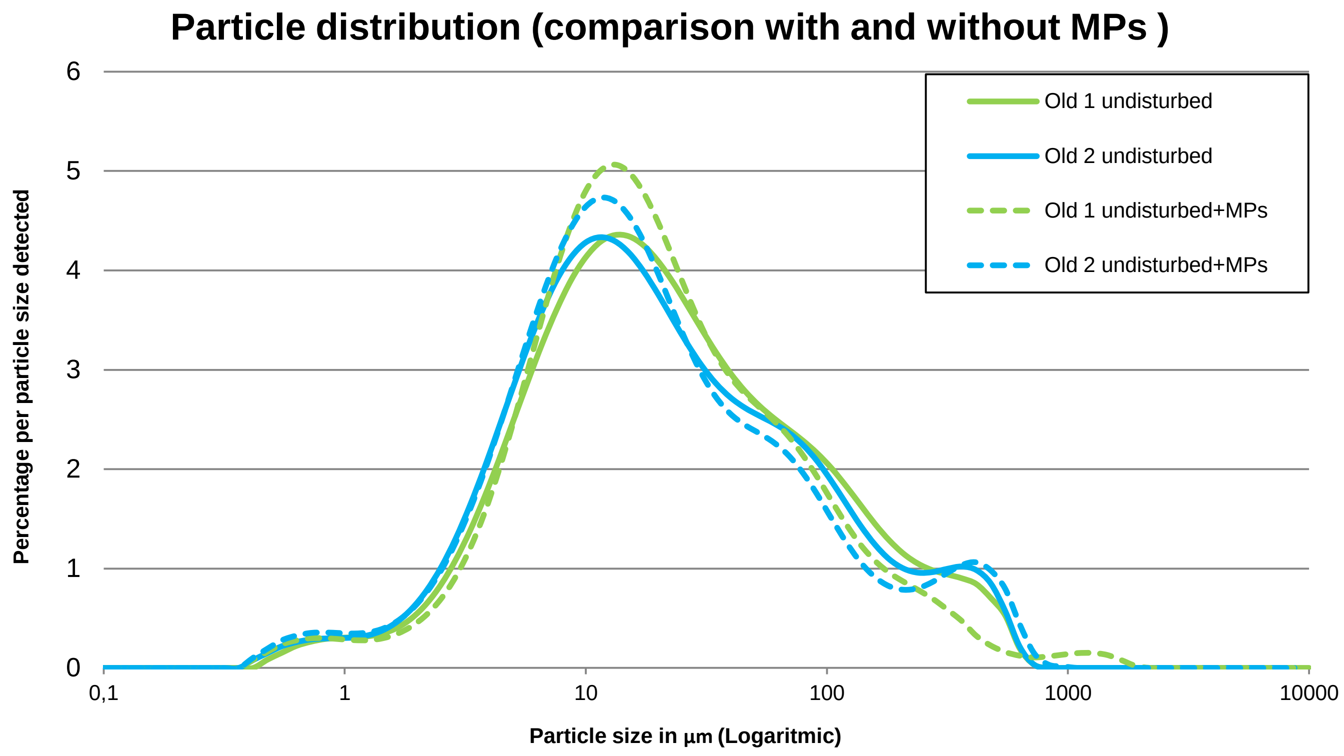

Figure: Particle distribution comparison with the addition of MPs.

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Results and discussion

… although there is evidence of floc formation (with and without MP’s) when comparing the particle size distribution directly after the start, and after 48 hours.

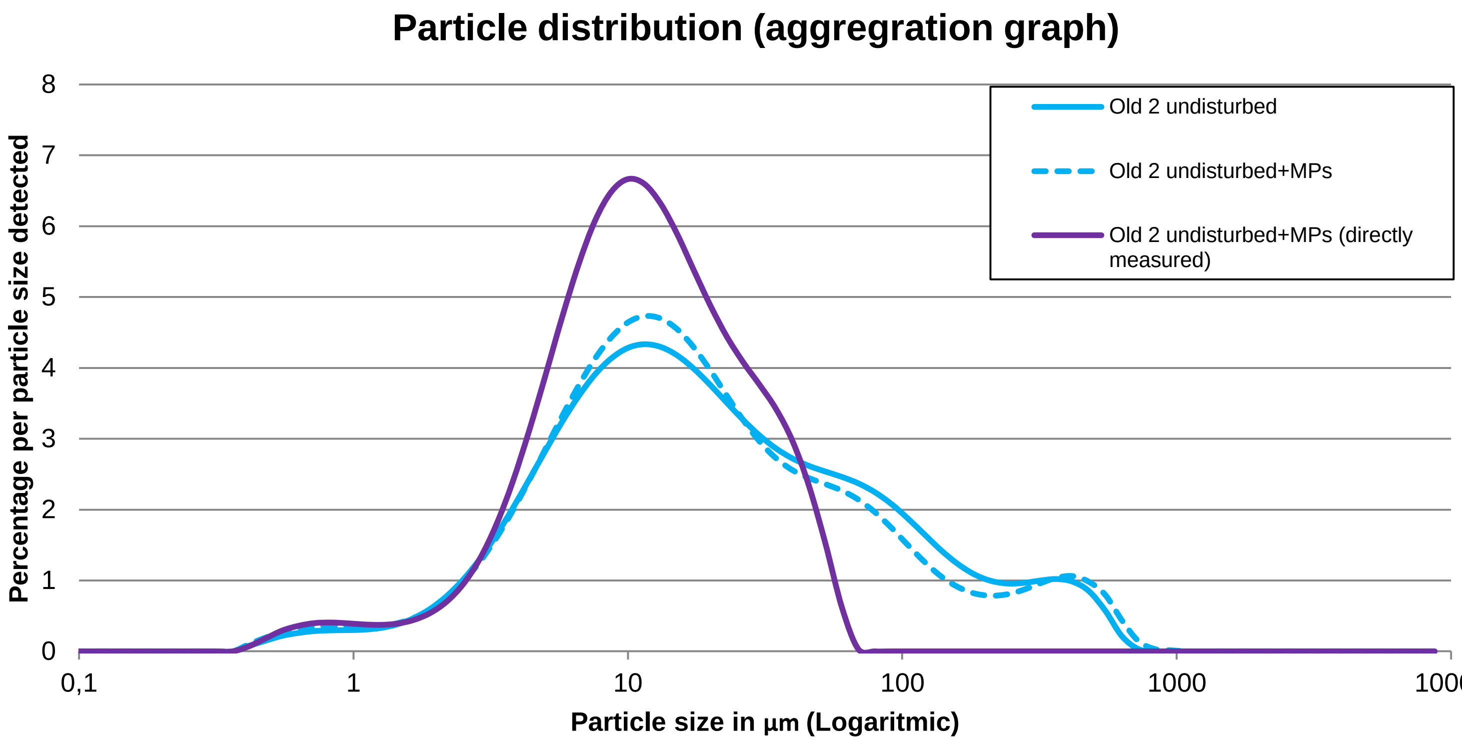

Figure: The effect of measuring the sample directly at the beginning and after emptying the column from the triplicate test.

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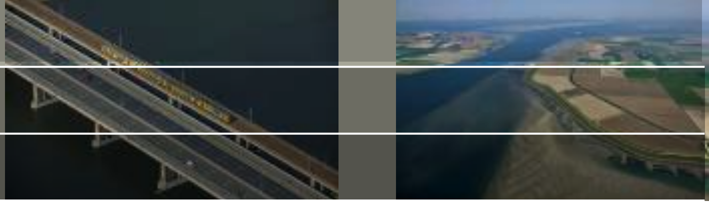
Results and discussion



The surface charge of the <53 μm sediment fraction (as measured by the zeta potential) with and without MP's might explain a stable floc formation (leading to an increased settling rate) in relative fresh water.

The zeta potential is < -25 / -30 mV up to ~5 mM NaCl (~0,3 ‰), which indicates a with a high stability for floc formation due to electroflocculation.

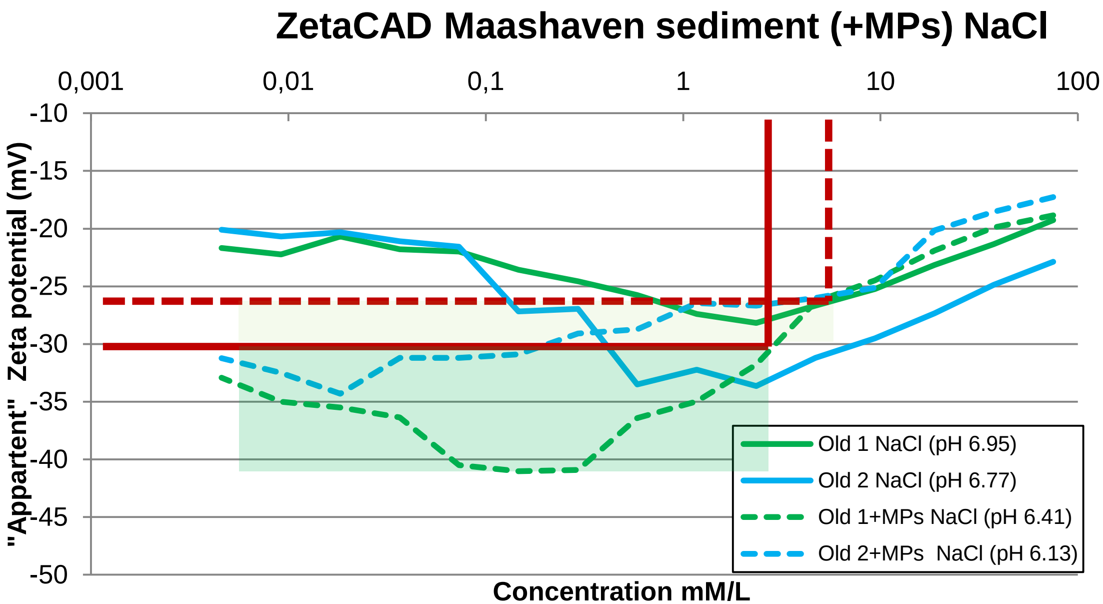


Figure: Zeta potential of the PoR sediments with the addition of aged MPs for NaCl only, the samples origin from the triplicate tests.

Since enhanced settling is also observed at a high salinity (at 3,0 ‰), the surface charge (MP's + sediment) alone can not explain the impact of MP's on settling.

Results and discussion

The MP's were also lighted with UV light. On its own, aged MPs has the tendency to float. Even though it is aged, the MP's are still quite hydrophobic. The UV lamp revealed that with old sediment, the MP's were settling.

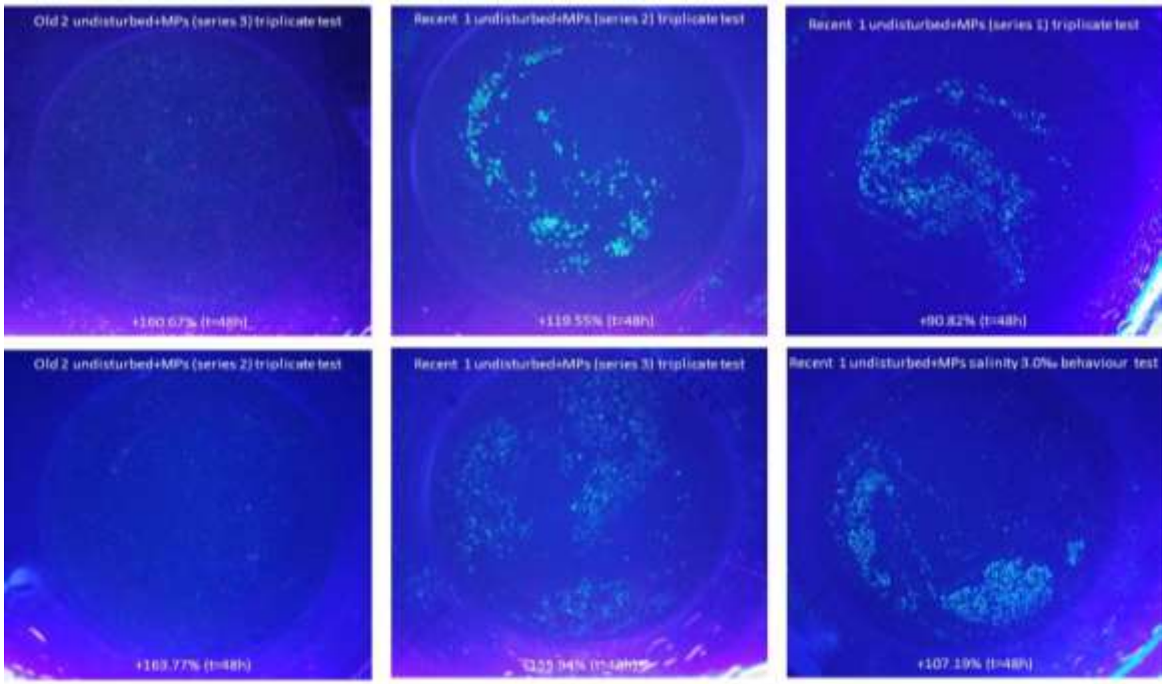


Figure: Top view of floating MP's after 48 hours of settling, different sediments

Barely any of the floating MP's were in the size range of 10-20 µm, indicating that especially the smaller MP's aggregate with the suspended sediment.

Potential impact on the settling behavior for Port of R’dam

Base on the observed increase in settling velocity of suspended sediments, the impact on the siltation in Port of Rotterdam was simulated using Delft 3D. The sediment settling velocity (v) was increased to replicate the presence of MP’s.

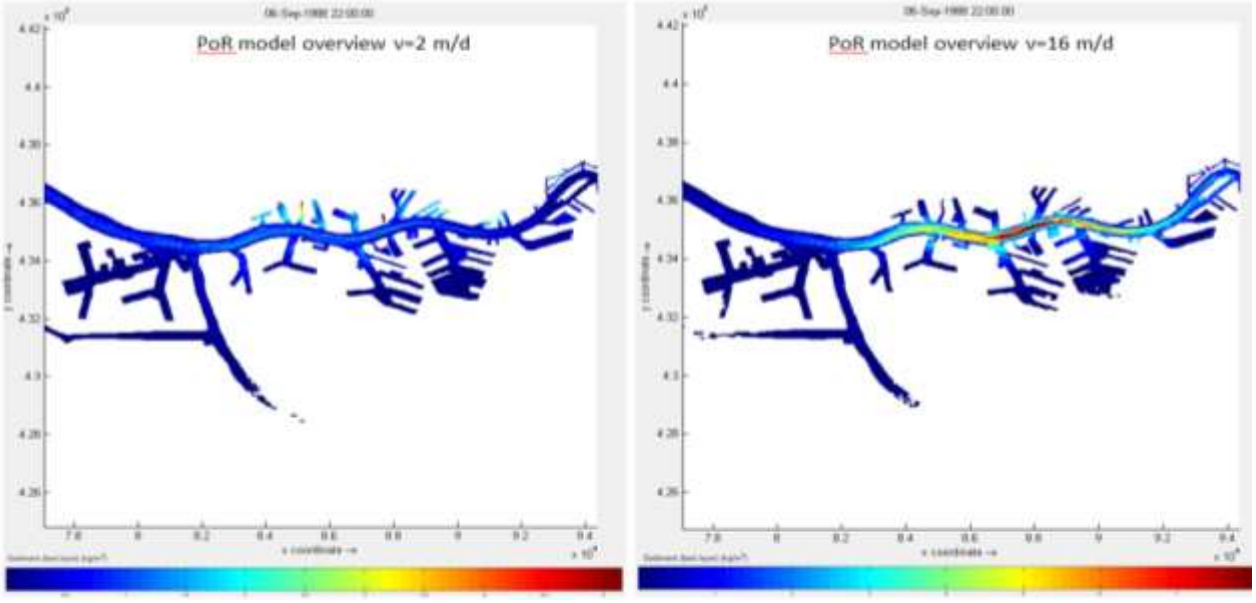


Figure: The shift in sedimentation when increasing the settling velocity

While the location of the increased sediment settling in the model is not realistic (central navigation channel), the model illustrates that MP’s might not only increase the sediment volume by adding to that volume by their own presence, but might also increase the settling rate of suspended sediments in ports.

Conclusions

More research is needed to better understand the parameters influencing the impact of MP's on sediment settling, like;

- The impact of MP's as flocculant (explored by measurement of the zeta potential).
- The impact of shear stress and floc stability (potentially explaining the model mismatch in sediment settling area's).
- The timescale of MP encapsulation, both in the water phase (suspended sediment) and in the sediment bed (impacting consolidation).
- The interaction with biological processes, like the role of MP's can have in forming biofilms which can glue together suspended sediments.

Kate Spenser (Queen Mary University of London) submitted a NERC proposal (EPPIC) to follow up on these questions on the impact of MP's on floc formation.

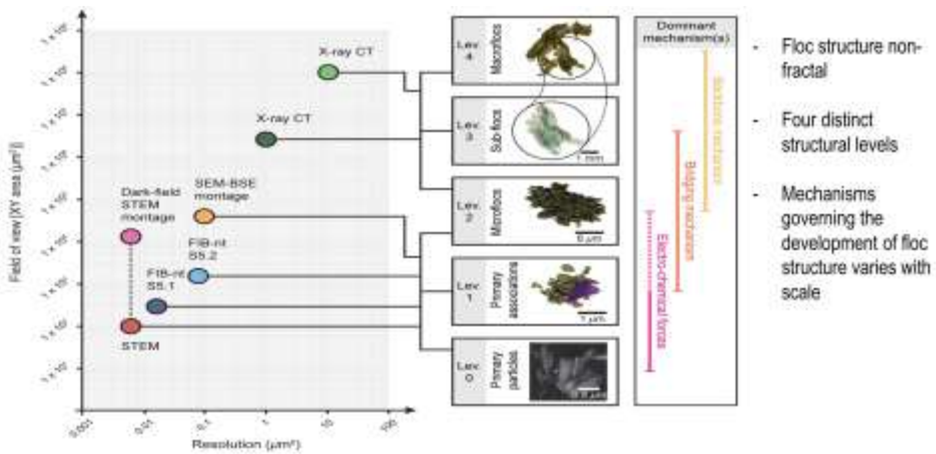


Figure: Kate Spencer, Floc hierarchical model

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