PlasticFreeDanube

DATA ON THE QUANTITIES OF PLASTICS RETAINED BY OR PASSING THROUGH HYDRO POWER PLANTS

Report

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Activity	4.3 Measurement of plastic passing the inlet grate of Freudenau or Gabcikovo
Detailoutput	D 4.3.2 Data on the quantities of plastics retained by or passing through hydro power plants

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1. Introduction

Although terrestrial environments and freshwaters are recognized as the origins and transport paths of plastics, the majority of research to date focuses on the marine environment (Horton et al., 2017). However, studies in freshwater environments have been rapidly advancing over recent years. Horton et al. (2017) gave a detailed overview of freshwater studies ranging from lakes, (e.g. Imhof et al., 2016; Fischer et al., 2016), to rivers (Baldwin et al., 2016; Dris et al., 2015; Faure et al., 2015; Lechner et al., 2014; Mani et al., 2015; McCormick et al., 2014 and Yonkos et al., 2014) and river sediments, (e.g. Klein et al., 2015; Horton et al., 2017). A number of studies have been performed that addressed the transport of microplastics in riverine systems. Measurements were undertaken in recent years in tributaries of the Great Lakes (Baldwin et al., 2016), the Seine River (Dris et al., 2015; Dris et al., 2018), various rivers in Switzerland (Faure et al., 2015), the Rhine River (Mani et al., 2015), various river sites near Chicago (McCormick et al., 2014) and the Danube River (Lechner et al., 2014). The researchers all used benthic nets (Lechner et al., 2014) or surface trawls as first used by Carpenter et al. (1972), described by Brown and Cheng (1981) and proposed as a standard methodology for surface waters by Lippiat et al. (2013). Moore et al. (2011) tried to address multiple depths by using different devices including a modified large Helley Smith sampler in concrete-lined creeks near Los Angeles. Also, Dris et al. (2018) addressed different depths in one point in the center of the Seine River by coupling a plankton net (addressing fibres) with a propeller-type current meter to sample down to 2 meters. But so far, only Liedermann et al. (2018) sampled the entire cross-section with a multi-point method to address microplastic transport in medium and large rivers. For the given research question, it is indispensable to address not only the water surface but the entire water column downstream of the hydropower plant. The high flow turbulence and turbulence caused by the turbines necessitates sampling in multiple depths. Therefore, a device is needed, applicable in highly turbulent environments which enables sampling in multiple depths. Furthermore, alternative measurement systems using GPS-tagged items to evaluate the influence of hydro power plants on macro plastic transport need to be investigated.

Within activity 4.3 “Measurement of plastic passing the inlet grate of Freudenau or Gabcikovo” a sampling device for direct sampling of macro plastics in free-flowing water bodies was developed and used to measure the amount of plastic passing the inlet grate of a hydropower plant as well as concentrations from the Donaukanal, a tributary entering the Danube River in the project reach. The device was developed, tested and adapted during measurements at different discharge stages. The methodology for measuring macro plastic transport was newly set up and optimized based on the device available for micro plastics. Net-frame diameter and mesh sizes had to be optimized to find the best possible assemblage for the given question.

A second approach, using GPS tagged items released upstream of the hydro power plant Freudenau was tested and optimized in order to obtain information on the possibility of macro plastic particles to pass the hydro power plant. Therefore, a long-term test using different available as well as self-constructed GPS systems with respect to hydrological conditions was performed in order to better understand plastic transport paths in fluvial systems.

The suggested measurement devices and methodologies both for net based measurements and GPS based tracer measurements are provided in deliverable D.4.3.1 “Sampling strategy and construction recommendations for direct macro plastic measurement devices in large rivers”. Within this report D.4.3.2 “Data on the quantities of plastics retained by or passing through hydro power plants” data of the conducted measurements within the PlasticFreeDanube project are presented.

2. Measurement sites

The conducted net based measurements within activity 4.3 “Measurement of plastic passing the inlet grate of Freudenau or Gabcikovo“ were carried out at 2 locations as depicted in Figure 1 (red crosses). At the location downstream of the HPP Freudenau, only one single point measurement could be carried out. At the second locations, the Donaukanal at Freudenauer Hafenbrücke, 2 cross-sectional measurement were conducted. Within the measurements, the equipment was therefore exposed to different hydrological and hydraulic conditions and various seasons. Besides, as indicated in Figure 1 (clue cross), a GPS tracer test in order to evaluate the influence of the HPP Freudenau on macro plastic transport was set up directly upstream of the hydro power plant.

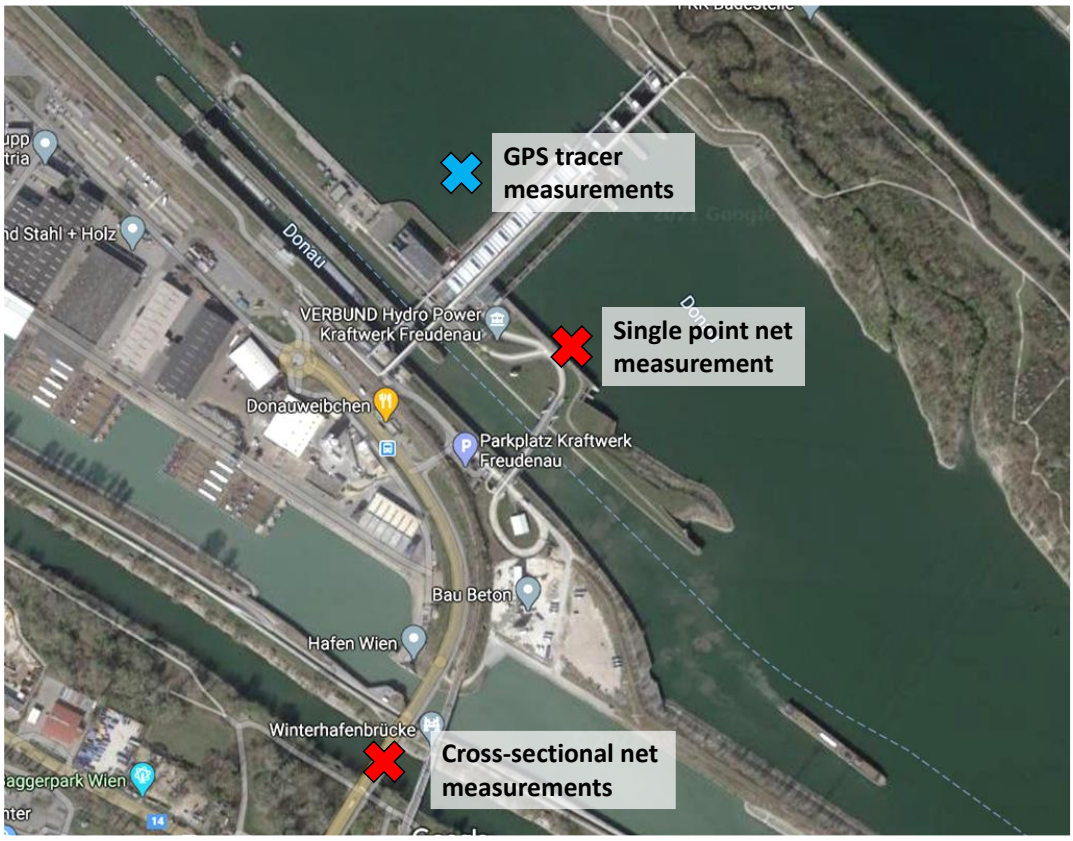


Figure 1 Locations of the net measurements (red crosses) – single point measurements downstream of the HPP Freudenau and cross-sectional measurement in the Donaukanal at Freudenauer Hafenbrücke and GPS tracer measurements (blue cross) at the HPP Freudenau (Source: Google maps)

3. Methodology

3.1. Net measurement

Since the measurements carried out served to generate plastic transport data on the one hand and to optimize the measuring device on the other, various stages of the measuring device were used in the course of the optimization process as depicted in Figure 2. The main distinction is towards the different frame sizes and mesh sizes that have been used. Frames with an opening of 600x600 mm were equipped for means of comparison with following mesh types:

- 250 µm with 34 % porosity
- 500 µm with 38 % porosity
- 2,43 mm with 44 % porosity
- 8 mm with very high but undefined porosity

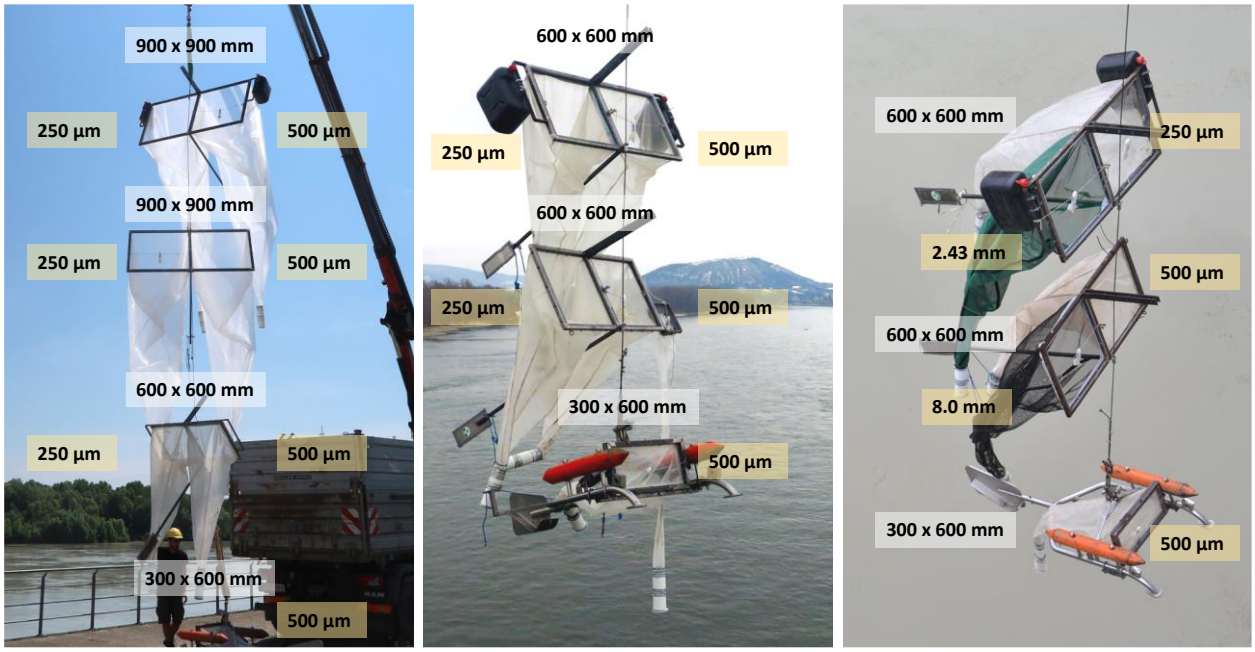


Figure 2 Different macro plastic measurement configurations tested and used during the PlasticFreeDanube project - left: configuration at the HPP Freudenau, centre: configuration for the first Donaukanal measurement, right: configuration for the second Donaukanal measurement

The mass transport of the plastic per time was measured by recording the measuring time per measuring point and determining the mass of the caught plastic. Following the methodology of suspended sediment measurements as described in ISO 4363 (2002), a multipoint measurement was performed in order to determine the spatial and temporal variability of the plastic transport. The final device and the suggested sampling methodology for macro plastic measurements are described in detail in deliverable D.4.3.1 “Sampling strategy and construction recommendations for direct macro plastic measurement devices in large rivers”.

3.2. GPS tracker

Besides direct net measurements throughout the water column, GPS based tracking of floating macro plastic items was performed within the PlasticFreeDanube project. As e.g. Tramoy et al. (2020) showed, this methodology can be a suitable method to evaluate macro plastic transport in riverine systems. By using this technology it was aimed to derive data on the influence of hydro power plants on plastic mass flows. 11 GPS transmitters from 3 different manufacturers were therefore mounted in macro plastic items (see Figure 4) released directly upstream of the HPP Freudenau for a long-term field survey. The used GPS trackers are listed below and depicted in Figure 4.

- Copenhagen Cobblestone GPS tracker
- modified WINNES
- INETIS GPS mini tracker

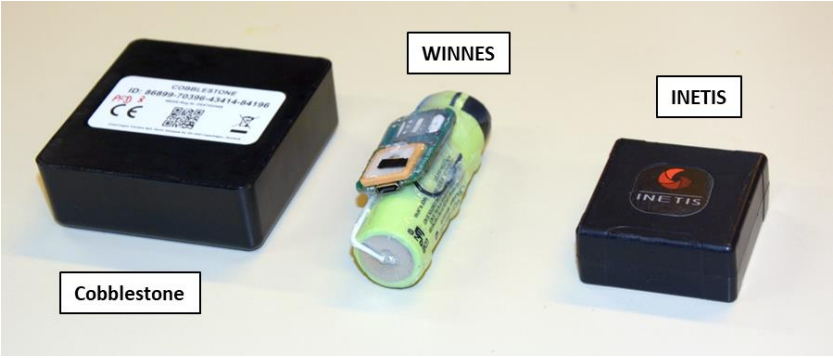


Figure 3 GPS trackers used within the PlasticFreeDanube project - left: Copenhagen Cobblestone, centre: modified WINNES, right: INETIS GPS mini tracker



Figure 4 Macro plastic items used for the GPS based field survey within the PlasticFreeDanube project

Detailed information on boundary conditions, the used trackers and towards the suggested sampling strategy for GPS based macro plastic measurements are provided in deliverable D.4.3.1 “Sampling strategy and construction recommendations for direct macro plastic measurement devices in large rivers”.

4. Results

4.1. Net measurement

Net based macro plastic measurements were conducted on 3 days at 2 different locations as listed below:

- 24.06.2019 – HPP Freudenau – 2700 m³/s discharge – single-point measurement
- 17.06.2020 – Donaukanal – 182 m³/s discharge – multi-point measurement
- 13.10.2020 – Donaukanal – 177 m³/s discharge – multi-point measurement

Measurements and analysis of the taken samples were performed according to the suggested sampling strategy described in deliverable D.4.3.1. The results of the carried out measurements are provided within this chapter revealing masses as well as composition of the found pollutants.

4.1.1. Composition of fluvial macro plastic

An analysis of the taken samples towards the composition, classification and distribution was performed in order to increase knowledge on the measured transported plastics. In Figure 5 a classification of the sorted plastic particles towards foils, fibres, fragments (>1 mm / > 1 mm) and polystyrol is presented for the measurement at the HPP Freudenau 24.06.2019 (left) and the two measurements at the Donaukanal – 17.06.2020 (centre) and 13.10.2020 (right). For all three measurements, a high number of recognized particles was classified as fragments larger than 1 mm. While the two samples at the Donaukanal show almost similar results towards the classification, the sample downstream of the HPP Freudenau is furthermore characterized by a large number of foils compared to the Donaukanal samples. At the same time, both samples at the Donaukanal seem to have o constant load of polystorol, whereas in the Danube this class is neglectable for the conducted measurement. Recognizable and quite similar parts of all three sample refer to fibres, while fragments smaller than 1 mm were rarely found.

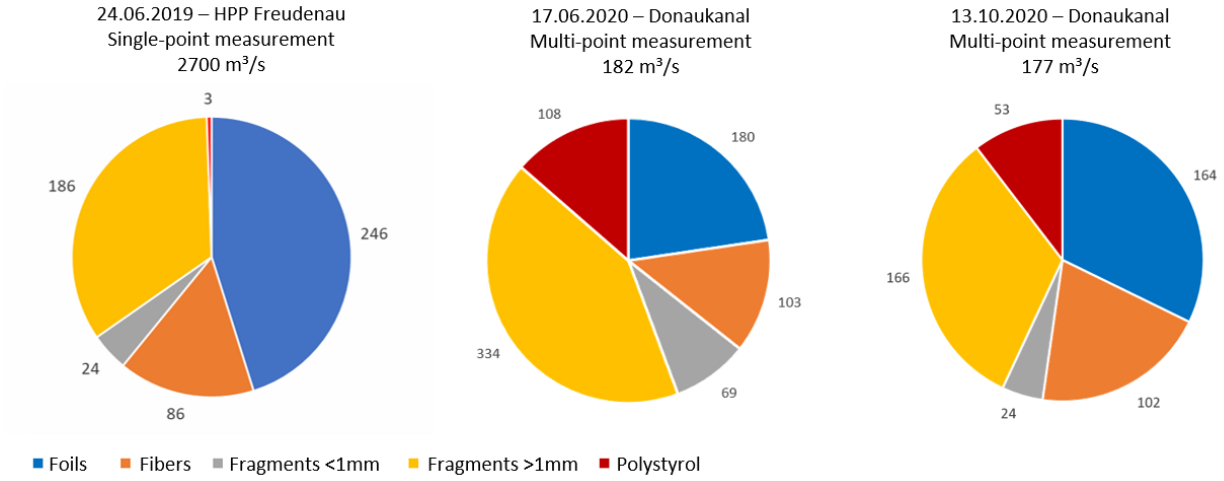


Figure 5 Classification of found plastic particles towards foils, fibres, fragments (>1 mm / > 1 mm) and polystyrol – left 24.06.2019 HPP Freudenau, center: 17.06.2020 Donaukanal, right: 13.10.2020 Donaukanal

An example for the vertical distribution of plastic particles measured on 17.06.2020 in the Donaukanal during a multi-point sampling is depicted in Figure 6. In the given example the distribution follows a typical vertical distribution of a velocity profile. As less water is filtered in the bottom near layer, also counted particles were found to be lower for this measurement based on hydraulic boundary conditions. This, however, is not representing the plastic concentrations, which are based both on particle flows and filtered water volume. Furthermore, this picture can differ between for every measurement, as plastic transport is was found to be highly heterogeneous.

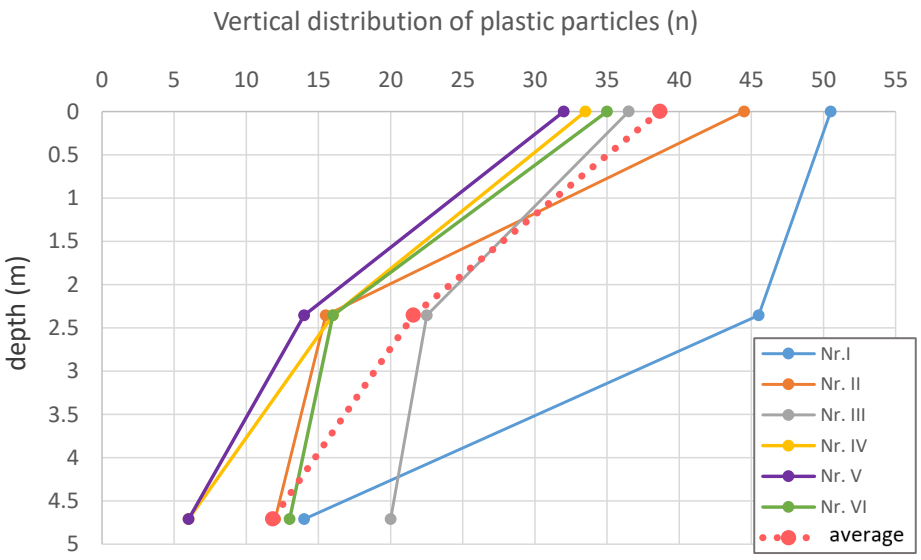


Figure 6 Vertical distribution of plastic particles - 17.06.2020 – Donaukanal Multi-point measurement

Figure 7 comprises the lateral distribution of plastic particles in the Donaukanal - 17.06.2020 (blue line) and 13.10.2020 (orange line). The graph shows, that for both measurements a quite similar distribution of plastic particles in the profile was recognized. The samples were conducted at same flow conditions in the Donaukanal, but in different seasons and different flow conditions in the Danube River, where the water is diverted from.

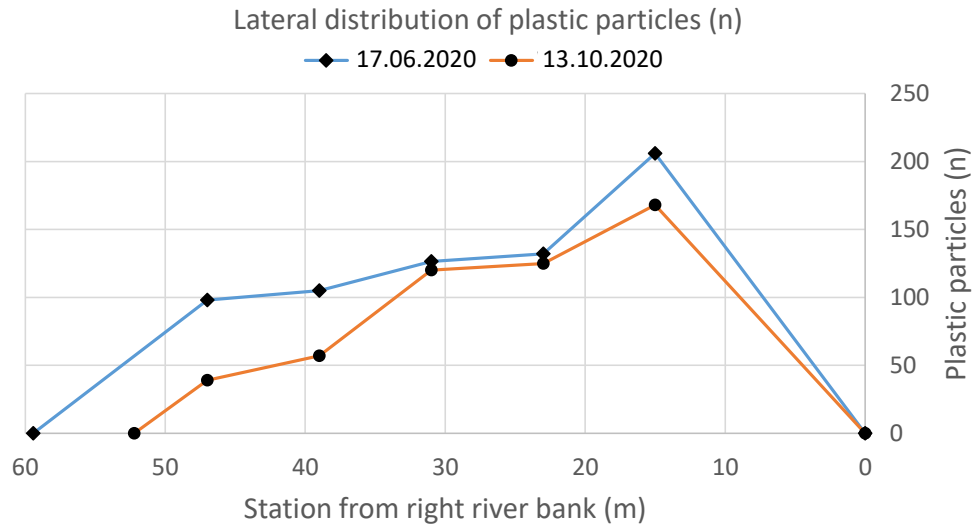


Figure 7 Lateral distribution of plastic particles in the Donaukanal - 17.06.2020 (blue line) and 13.10.2020 (orange line)

In Figure 8 the average number of total plastic particles (blue) per measurement found at the HPP Freudenau during the measurement on 24.06.2019 is plotted against the average number of macro plastic particles. In the ground layer macro plastic accounted for 33 % of the total found particles, while in the top layer around 60 % of the particles were classified as macro plastic particles. One of the reasons therefore might be the large number of foils within the samples, which are likely to be transported in the uppermost part of the water column under the given hydraulic conditions.

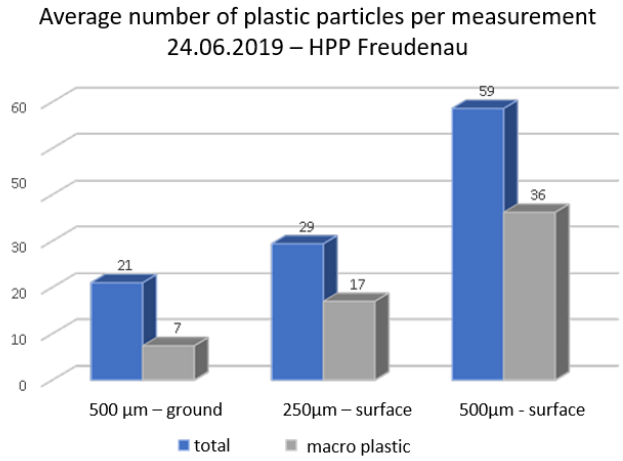


Figure 8 Average number of plastic particles per measurement found at the HPP Freudenau - 24.06.2019 - total (blue) and macro plastic (grey)

4.1.1. Macro plastic transport

In order to determine the mass flows of plastic during the conducted measurements, analysis and calculation was performed according to deliverable D.4.3.1. Besides the calculation of the total amount of plastic flow, for the measurements at the Donaukanal it was distinguished between concentrations of total plastic and macro plastic particles larger than 1 cm. The calculated concentrations are depicted in Figure 9 to Figure 12. For the first measurements on 17.06.2020 results are presented for the 250 µm and 500 µm net (Figure 9 and Figure 10), for the second measurement at the Donaukanal on 13.10.2020 the results are presented towards the 4 used mesh types in Figure 11 and Figure 12. While in the first measurement at the Donaukanal highest concentrations were recognized at the surface, the second measurement draws a much more heterogeneous picture of the vertical distribution of concentration as mentioned previously.

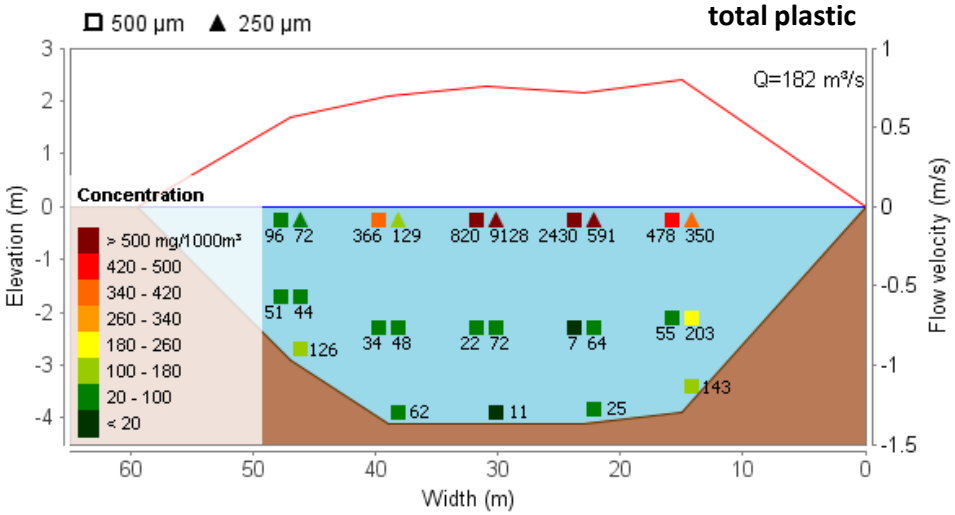


Figure 9 Measured concentrations – total plastic - 4 mesh types (250 µm, 500 µm, 2.43 mm, 8 mm) – Donaukanal - discharge 182 m³/s – 17.06.2020

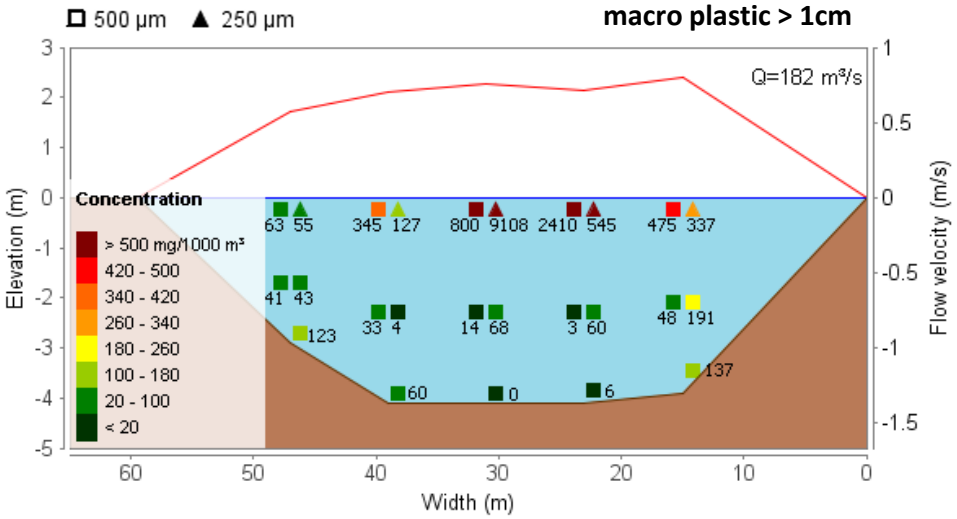


Figure 10 Measured concentrations – macro plastic - 4 mesh types (250 µm, 500 µm, 2.43 mm, 8 mm) – Donaukanal - discharge 182 m³/s – 17.06.2020

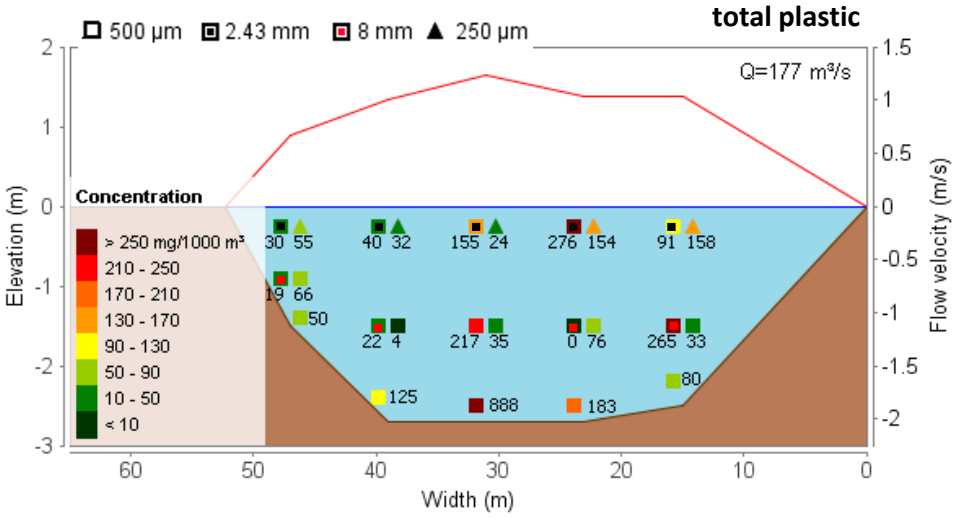


Figure 11 Measured concentrations – total plastic - 4 mesh types (250 µm, 500 µm, 2.43 mm, 8 mm) – Donaukanal - discharge 177 m³/s – 13.10.2020

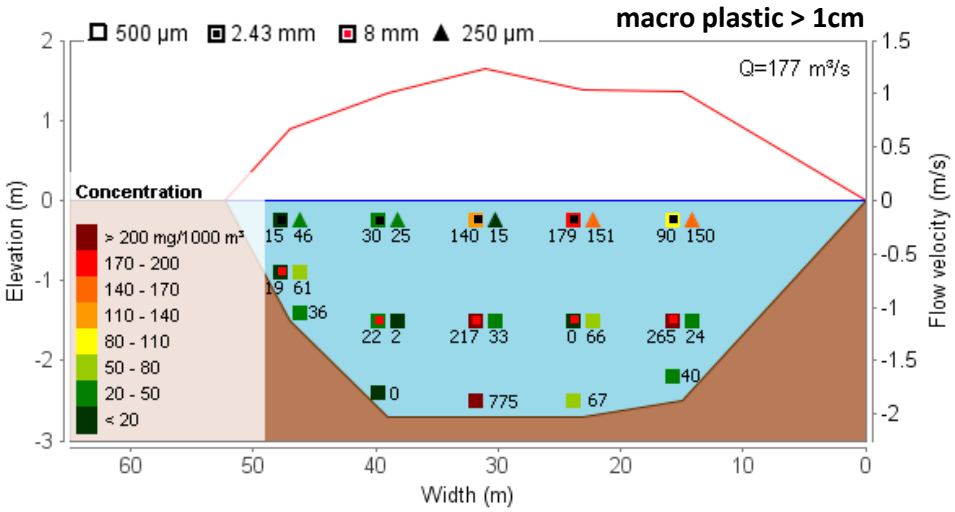


Figure 12 Measured concentrations – macro plastic - 4 mesh types (250 µm, 500 µm, 2.43 mm, 8 mm) – Donaukanal - discharge 177 m³/s – 13.10.2020

Based on the determined concentration the plastic transported was calculated as shown in Table 2. For the given example, the total plastic flow including micro and macro plastic is presented for the measurement in the Donaukanal on 17.06.2020 at a discharge of 182 m³/s amounting to 5.29 kg per day. Besides the total plastic also the flux of macro plastic was determined for the conducted measurements in the Donaukanal.

Table 1 Calculation of plastic transport – Donaukanal - discharge 182 m³/s – 17.06.2020 – total plastic

	station	total depth	sampling depth	plastic concentration	flow velocity				plastic load
	b	tw		s0	v	s0*v		qsi	Qsi
	m	m	m	g/m³	m/s	g/s m²	g/s m	g/s m	g/s
right shore line	0.00								0.01
intersection 1	15.00	3.90	0.25	0.0	0.800	0.00033	0.00008	0.00071	0.00912
			2.10	0.0	0.845	0.00011	0.00041		
			3.70	0.0	0.937	0.00013	0.00019		
							0.00003		
intersection 2	23.00	4.10	0.25	0.0	0.780	0.00118	0.00029	0.00157	0.02450
			2.30	0.0	0.714	0.00003	0.00123		
			3.90	0.0	0.902	0.00002	0.00004		
							0.00000		
intersection 3	31.00	4.10	0.25	0.0	0.706	0.00351	0.00088	0.00455	0.01957
			2.30	0.0	0.786	0.00004	0.00364		
			3.90	0.0	1.000	0.00001	0.00004		
							0.00000		
intersection 4	39.00	4.10	0.25	0.0	0.724	0.00018	0.00004	0.00034	0.00187
			2.30	0.0	0.743	0.00003	0.00021		
			3.90	0.0	0.850	0.00005	0.00007		
							0.00001		
intersection 5	47.00	2.90	0.25	0.0	0.519	0.00004	0.00001	0.00013	0.00081
			1.70	0.0	0.723	0.00003	0.00006		
			2.70	0.0	0.520	0.00007	0.00005		
							0.00001		
intersection 6	59.43								

cross sectional plastic flow (g/s):	0.06
kg/s	0.00
kg/h	0.22
kg/d	5.29
g/h	220
discharge (m³/s):	182
mean plastic concentration (g/1000m³):	0.3363

In Figure 13 the results of the calculated daily macro plastic transports measured at two dates at the Donaukanal separated in total plastic and macro plastic larger than 1 cm are presented. During both measurements most of the transported plastics was characterized as macro plastic with a range of 90 to 97 % of the total plastic transport. While in the first measurement more than 5 kg of daily plastic flow in the Donaukanal was found, the second measurement reveals a daily plastic load of around 1 kg. Reasons therefore might be due to seasonal effects or natural fluctuations of the load.

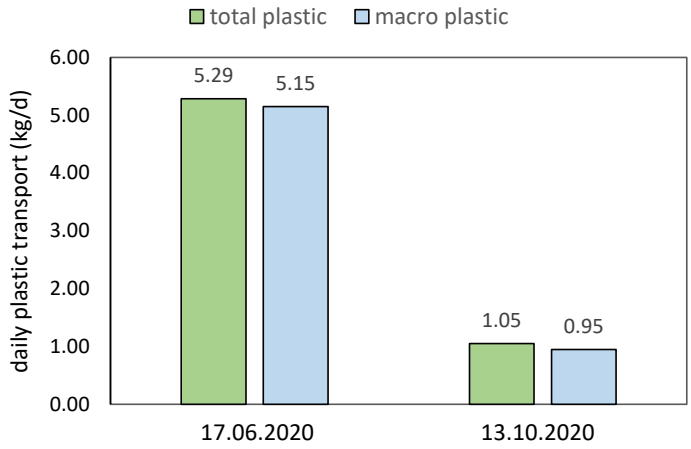


Figure 13 Calculated plastic transport - Donaukanal - left: 17.06.2020, right: 13.10.2020 - total plastic (green) and macro plastic larger than 1 cm (blue)

For the single point measurement downstream of the HPP Freudenau an estimation of the mass transported during the day was performed based on the depth-averaged plastic concentration distributed over the measuring vertical. Concentrations for the used nets are depicted in Figure 14, the average concentration amounts to $2{,}916*10^{-4}$ g/m³.

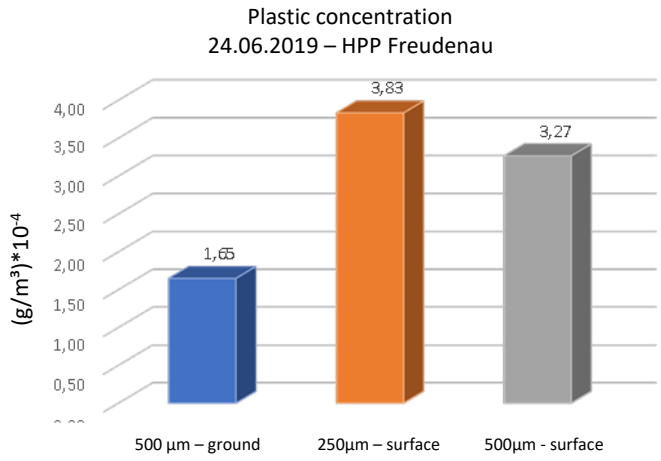


Figure 14 Plastic concentrations for the single point measurement at the HPP Freudenau - 24.06.2019

With respect to the average discharge (Q_m) of 2700 m³/s during the measurement and the plastic concentration (C_m), the daily transport was calculated as shown in Table 2 amounting to 68 kg/d.

Table 2 Calculation of daily plastic transport in the Danube River - HPP Freudenau - 24.06.2019

daily transport [kg] = Cm * Qm * (60*60*24)/1000		
C_m [g/m³]	Q_m [m³/s]	daily transport [kg/d]
$2{,}916*10^{-4}$	2700	68.03

All three samples from the Donaukanal and downstream of the HPP Freudenau were taken at different hydrological, seasonal and temporal conditions. Relating the daily plastic loads to the concentrations, however, shows, that the values are in a similar range and support each other. A significant higher input of plastic along the Donaukanal was not proven within the frame of the carried-out measurements. However, the measurements only give a first insight about the significance of the Donaukanal, which is flowing through the densely populated inner city of Vienna with a wide range of critical issues like recreation and waste water treatment plants.

4.2. GPS tracker

Table 3 contains an overview of the GPS tagged items released directly upstream of the HPP Freudenau. 5 INETIS, 3 Cobblestone and 3 WINNES transmitters were mounted into bottles, shoes, tennisballs and XPS packs. All items were introduced into the Danube River on 18.12.2020, dates on the last received signal and further information about the fate of the item is also given in Table 3.

Table 3 Overview of GPS tagged items released upstream of the HPP Freudenau

GPS-tag	Name	Item	Start	End	Information
INETIS	84900	bottle filled	18.12.2020	30.12.2020	-
INETIS	07040	shoe	18.12.2020	30.12.2020	removed at grate
INETIS	46339	small botttle	18.12.2020	30.12.2020	-
INETIS	37426	tennis ball	18.12.2020	no data	-
INETIS	76880	bottle empty	18.12.2020	28.12.2020	-
Cobblestone	PFD1	XPS	18.12.2020	19.01.2021	-
Cobblestone	PFD2	XPS	18.12.2020		passed HPP 25.01.2021
Cobblestone	PFD3	bottle filled	18.12.2020	19.01.2021	-
WINNES	18473	tennis ball	18.12.2020	14.01.2021	-
WINNES	18453	shoe	18.12.2020	10.01.2021	-
WINNES	18226	bottle empty	18.12.2020	07.01.2021	-

Figure 15a depicts the position of introduction upstream of the HPP Freudenau on the left river bank. Due to the hydraulic situation the GPS-marked items drifted to the right bank side directly at the grate of the hydro power plant as visualizations of the detected positions in Figure 15b (INETIS), Figure 15c (WINNES) and Figure 15d (Cobblestone) show. This also proves the functionality of the real time transfer of positions for the used products. As to be seen in Table 3, the shortest measurement duration was recognized for the INETIS trackers ranging between 10 and 12 days, the WINNES tracker had a lifetime between 20 and 30 days, whereas the Cobblestone tracker sent signals also after 30 days. For most of the GPS tags all positions were recognized directly at the grate of the HPP until they stopped sending. One of the trackers was obviously removed at the grate, as it was found in the containers during sampling and sorting analysis. Another tracer, however, was overcoming the barrier and was detected downstream of the HPP Freudenau as depicted in Figure 16. The detected Cobblestone tracer was mounted in an XPS pack and was transported around 66 km within a timeframe of 6 days from upstream of the HPP Freudenau until the reservoir of the HPP Gabcikovo in Slovakia.

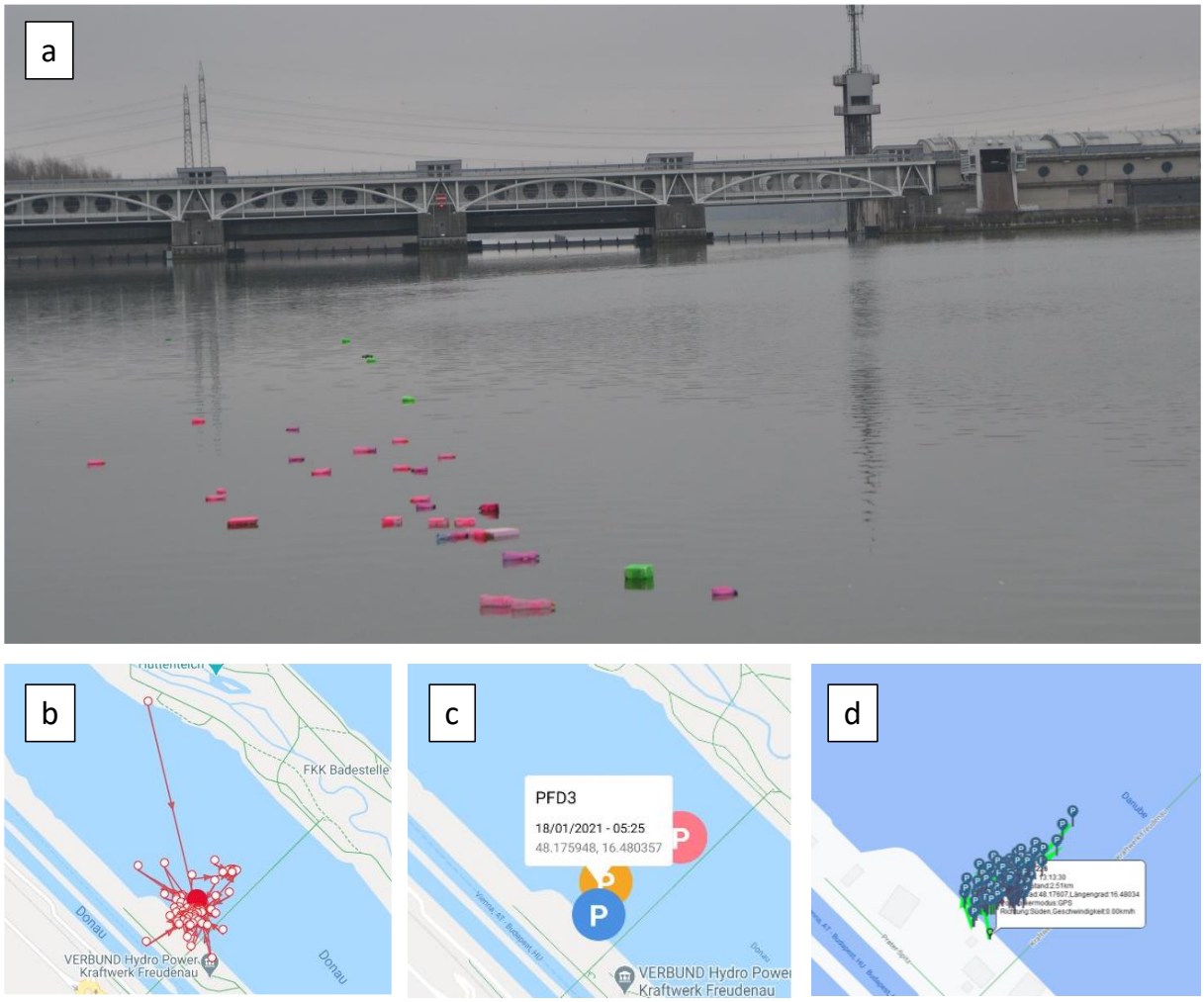


Figure 15 Introduced GPS-tagged and non GPS-tagged macro plastic tracers (a) and visualisations of the recorded GPS positions for (b) INETIS, (c) WINNES and (d) Cobblestone trackers

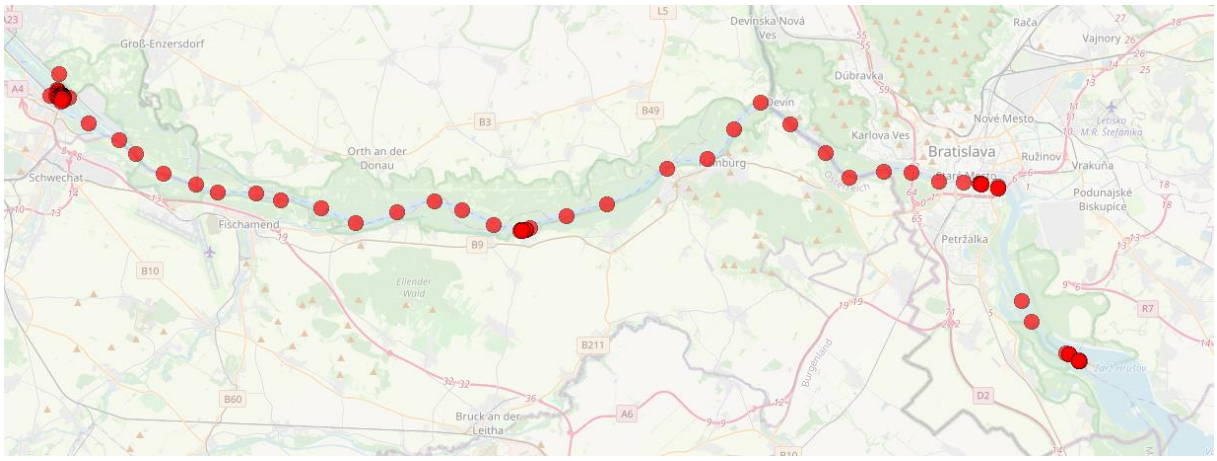


Figure 16 Detected track of the Cobblestone tracker passing teh HPP Freudenau

A temporal analysis of the mentioned tracker with respect to the hydrological situation for the tracker that passed the HPP Freudenau are presented in Figure 17. The blue line representing the Danube discharge reveals, that in the beginning of the tracer test a period of discharges around regulated low flow level (RNQ) occurred, followed by an event with higher discharge. The peak of this event was detected on 30.01.2021 with a flow of 3580 m³/s and therefore above the capacity of the HPP Fredenau of 3000 m³/s as indicated in the graph. Discharges above the capacity lead to an overflow of the weirs and are therefore considered as main drivers for the through-passing of macro plastic items. The green line, however, indicates the distance from the starting point at the hydro power plant and shows, that the tracker already passed the barrier before the discharge event leading to overflow of the weirs. During the flood wave the tracker though was remobilized again and transported further downstream into the reservoir of the HPP Gabcikovo.

Although the field test based on GPS tagged items only comprises first impressions, the results gives an insight towards the influence of hydro power plants on macro plastic transport:

- Plastic items tended to drift towards the grate and stayed there during low flow
- The removed tracker shows, that cleaning facilities at HPP can serve to withdraw plastic from the system
- The passing through tracker proves, that macro plastic can overcome barriers like hydro power plant even during low flow conditions
- Passing through of items via overflow of the gates during higher discharge events (in the case of HPP Freudenau > 3000 m³/s) is very likely and has to be assessed in future projects

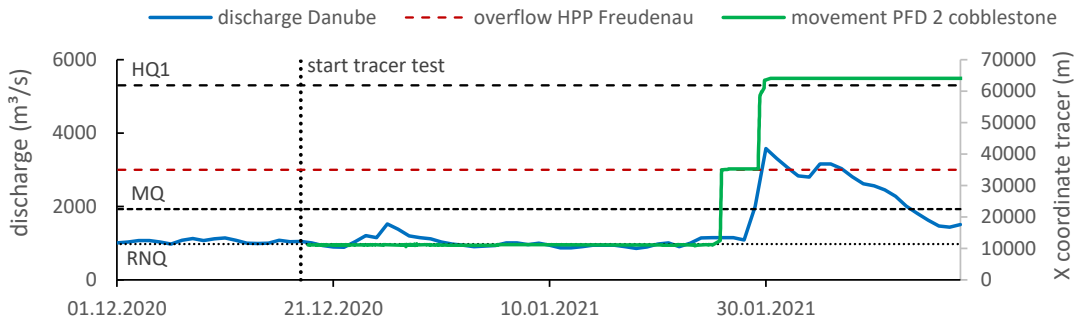


Figure 17 Travel distance of the tracker that passed the HPP Freudenau (green) and hydrograph of the Danube River (blue)

5. Summary and conclusion

Within this report Data on the quantities of plastics retained by or passing through hydro power plants are provided, namely for (i) direct single point and cross-sectional net based measurements and (ii) GPS based tracking of plastic items.

During the project three direct net based measurements were conducted. One single-point measurement directly downstream of the HPP Freudenau as well as two cross-sectional multi-point measurements in the Donaukanal. An analysis towards the particle size revealed, that related on the mass during the 2 measurements at the Donaukanal over 90 % of the plastics were larger than 1 cm and characterized as macro plastic therefore. Also downstream of the HPP Freudenau, a large number of macro plastic particles based on particle counts was recognized. The daily transport during the measurement downstream of the hydro power plant amounted to 68 kg per day, while at the Donaukanal, with much lower discharge, daily yields of 1 kg respectively 5 kg per day were recognized. Samples from the Donaukanal and downstream of the HPP Freudenau were taken at different hydrological, seasonal and temporal conditions. Relating the daily yields, however shows, that the values are in a similar range and support each other. A significant higher input of plastic along the Donaukanal was not proven within the frame of the carried-out measurements.

Further analysis of the taken samples towards the composition, classification and distribution were performed in order to increase knowledge on the transported plastics measured. While all three samples showed high amounts of fragments larger than 1 mm and very rare number of fibres, in the Donaukanal a constant load of polystyrol was recognized compared to the measurement in the Danube downstream of the HPP Freudenau. The samples from the Danube, therefore, were characterized by a high number of foils. Towards the spatial distribution it was found, that plastic partly follows a flow velocity like profile with higher transport rates and concentrations in the centre part and on the surface of the river. However, plastic fluxes are very heterogeneous due to hydrological, seasonal and temporal impacts.

Tracking of macro plastic by means of GPS transmitters are an upcoming methodology to get more insight into behaviour of riverine pollution. Therefore frequently found macro plastic items were fitted with GPS transmitters and introduced into the Danube River directly upstream of the hydro power plant Freudenau. Several available GPS systems were used within the survey. Although the field test based on GPS tagged items only comprised first impressions, the results give an insight towards the influence of hydro power plants on macro plastic transport. The introduced macro plastic items tended to drift towards the grate and stayed there during low flow. During sampling and sorting of waste from the grate of the hydro power plant one GPS tagged item was also removed, showing, that cleaning facilities at a HPP can serve to withdraw plastic from the system. One of the trackers, however, passed the hydro power plant and made its way towards the reservoir of the hydro power plant Gabcikovo in Slovakia. This tracker proves, that macro plastic can overcome barriers like hydro power plant even during lower flow conditions. A much higher rate of plastic passing hydro power plants via overflow of gates during high discharge events is very likely. Therefore, for future projects, this issue has to be assessed.

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