PlasticFreeDanube

DESIGN RULES FOR HYDRAULIC ENGINEERING STRUCTURES FOR PLASTIC ACCUMULATION

Report

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1. Introduction

Within the project „PlasticFreeDanube" an analysis of the main sources, inputs and pathways of plastic waste in the Danube and on its river banks was performed. Within the activities 3.6 "3D hydrodynamic modelling of selected plastic accumulation zones" and 3.7 "Particle tracing and hydraulic characterization of plastic accumulation zones" it was aimed to describe fluvial processes related to plastic waste in river systems by the means of numerical simulation and particle tracing. To simulate the particle pathways, a simplified numerical tracer model is applied. The areas selected for the investigation were defined according to the findings of activity 3.5 "Map of plastic accumulation zones", where typical plastic accumulation zones were evaluated according to hydromorphological aspects. 2D and 3D numerical models were set up, described and analysed and build the basis for the identification of parameters leading to accumulations of plastic particles. Furthermore, field test revealing sophisticated process understanding of plastic particles entering a river system were conducted with GPS-tagged floating items.

The gathered results about the behaviour of floating plastic particles in flowing waters allow a description of the hydraulic and morphological parameters of typical accumulation zones such as secondary flows, backwater, groyne shapes and angles, bank slopes etc. with respect to the natural flow regime.

Based on the results of the previous activities, possible adaptations to hydraulic engineering structures that enhance plastic accumulation are presented here. Furthermore, as results of the project indicate, measures in term of maintenance and technical solutions to take out plastic from the river system can be considered.

2. Identified parameter leading to macro plastic accumulation

Within this chapter, the identified parameters and processes leading to macro plastic accumulations in the investigated area are presented. The work carried out has shown that the accumulation processes observed can be basically divided into three main groups, namely bank-near accumulation, floodplain accumulation and accumulations related to hydraulic structures.

2.1. Bank- near accumulation

- Classification of long-term discharge data on a monthly basis reveal, that due to the hydrological regime the discharge of the Danube River can be separated a **spring/summer and an autumn/winter period. During these most frequent occurring discharge levels plastic accumulates on the banks**, as often found during sampling campaigns
- A **methodology for quantifying bank-near accumulation** was developed revealing potential amounts of macro plastic accumulations in the bank near zone. **Identified parameters** for the accumulations on the shore line are **falling water conditions** as well as **wave splash**. A large number of pieces and a high mass of macro plastic is in constant **exchange between transport in the main channel and accumulation** on the shores. With respect to the hydrological conditions, this knowledge can improve sampling efforts on river bank sections.

2.2. Accumulation behaviour related to hydraulic structures

- A flow chart regarding water age and vortex formation identifying parameters leading to **accumulation effects related to engineering structures** depended on discharge levels was developed based on virtual particle flow simulations
    - **Marginal macro plastic accumulation** was observed **during low water conditions** due to low water exchange between main channel and groyne field
    - **Initial accumulations** in the bank-near area occur **at mean water level** due to moderate vortex formations with more exchange between main stream and groyne fields
    - Entire overflow of engineering structures and subsequent **remobilisation** was observed at **discharges above mean water level**
    - **Water level lowering** was identified to have a high probability for **macro plastic to accumulate** within the groyne fields
- A **quantification of mass flows** of virtual particles by means of particle simulation **in a 7 kilometer idealized channel** identified parameters of accumulations related to engineering structures
    - Between low water and mean water discharge **most particles (98 %)** in the main channel **pass through the section** without accumulation in groyne fields when **evenly distributed** over the cross section
    - Particles **launched near the bank** showed a high probability to accumulate again between low water and means water discharge. On the left bank characterized by 2 groyne fields (each having 6 single groynes) between **40 % and 60 % accumulated in the groyne fields**
    - **Highest accumulation** potential was found in the **centre of the groyne fields**
- A series of **tests using GPS-tagged floating items** was performed to investigate the accumulation behaviour in the field showing good correlation with simulated particle tracks
    - Macro plastic tends to **stay on the river bank where it is introduced** into the system. Particle tracks run mostly **bank-parallel** without switching to the opposite riverbank indicating, that **pollution from right bank tributaries** (Donaukanal, Schwechat and Fsicha) are likely to **end up on the right river bank of the Danube**.
    - M**ost of the strandings** were detected at **fixed banks (41 %) and groyne fields (29 %)**, based on the fact, that between Vienna and Bratislava around **70 % of the river banks** are characterized by **fixed embankments** with riprap stones with numerous groyne fields
    - **Travel distances** until stranding with respect to the used item (tennis ball, flipflop, bottle filled, bottle empty) ranged between 7.1 km to 15.7 km with an **average value of 10.4 km**
    - **Higher stranding possibility** was observed **at higher discharges** due to more interaction between main channel and groyne fields

2.3. Floodplain accumulation

- **No clear relation** between accumulation data and h**ydraulic parameters** like water depth, flow velocities and specific discharge was found

- **Clear correlation** between floodplain accumulations and **vegetation and woody debris** was found. Maximum concentrations of 1130 g/m² compared with bank-near maximum concentration of 20 g/m² indicate, that the **floodplain area works as a** filter due to its vegetation.
- Flood events and the related remobilisation of plastics in combination with **overtopping of the hydro power plant Freudenau** are a **main factor** for floodplain accumulation
- Floodplain particle flow paths show, that **particles are likely to drift into side arms** as well as into **natural sinks** of the floodplain area where accumulation was observed both in the model as well as in nature

3. Suggested measures for a reduced macro plastic occurrence

Within this chapter measures for a reduced macro plastic occurrence based on the findings described previously are described. As indicated in the introduction and proven by the parameters defined based on the project results, structural, technical and furthermore non-structural maintenance measures are suggested to reduce plastic pollution in the project area and beyond.

3.1. Structural measures

Several findings towards an improved accumulation potential related to river engineering structures were observed in the field and simulated by means of hydrodynamic numerical modelling. The resulting suggestions presented below, however, provide a starting point towards the implementation of engineering measures. It is suggested, to further develop the findings using sophisticated large scale physical modelling in order to cross-validate, prove and improve these measures and close knowledge gaps.

3.1.1. Centre groyne field within a structure of multiple groynes– low water to mean water level

Numerical simulations revealed, that engineering measures have a large impact on accumulation tendencies due to its flow diverting effects. It was proven, that groyne fields tend to have a much higher effectiveness than single structures, as indicated in Figure 1. In particular, the centre groynes of each groyne field showed the highest percentage of detected particles in all simulated cases as long as the structures are not submerged. Groyne fields are a very common hydraulic engineering structure at the Danube River east of Vienna. Therefore, groyne fields can work as trapping structures with respect to the given hydrology – e.g. below mean water level in the project area. The implementation of such structures directly before or after confluences can reduce the macro plastic input from tributaries. The investigated orthogonal groyne types at with a crest level around mean water level represent the typical groynes found in the project reach. It is suggested to further analyse the influence of layouts (e.g. inclined, declined) as well as different crest levels (e.g. low water groynes).

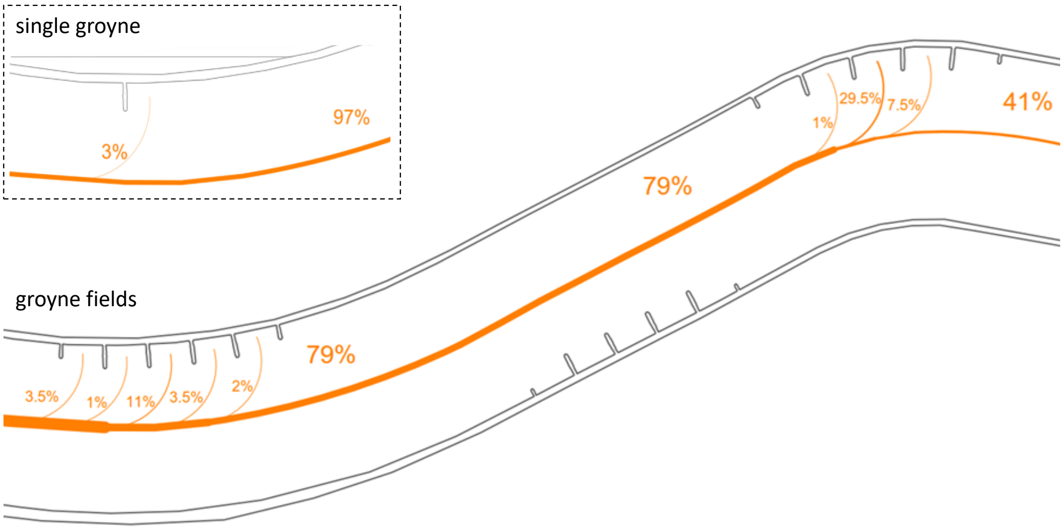

Figure 1 Effectiveness of groyne layouts towards accumulation potential of simulated macro plastic particles

3.1.2. Litter filtering groyne – above mean water level

Macro plastic transport was found to be increased at higher discharges due to higher input and remobilisation effects. At the same time discharges above mean water level leads to overflow of groyne structures as depicted in Figure 2. Therefore, during higher discharges, the trapping characteristic of groynes is not given. However, a large portion of partial flow is running over the groynes as shown in Figure 2 bottom. An engineering measure using these characteristic in order to reduce macro plastic pollution can be the implementation of vegetation on groyne crests. Vegetation was found to have a huge impact on accumulation behaviour due to its filtering effect. The partial discharges flowing over the groyne crests would then subsequently cross the crest vegetation and filtered. Filtering effects as well as influence on hydrodynamics and morphodynamics of such measures needs to be tested and optimized within the scope of sophisticated physical models in advance and monitored before, during and after implementation.

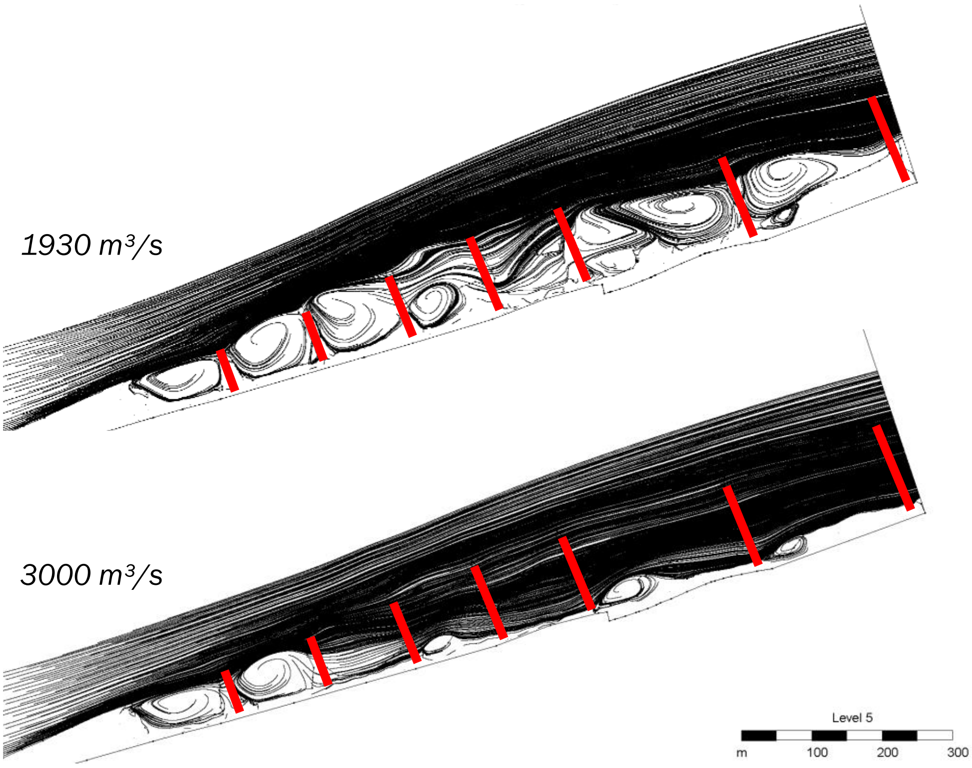

Figure 2 Particle tracks simulated at 1930 m³/s (up) and 3000 m³/s (bottom)

3.2. Technical measures

As the topic of plastic pollution of freshwater systems gained importance, also technical solutions to prevent or reduce macro plastic from our environment arose. A comprehensive overview comparing different types of approaches is given by Helsinki et al. (2021). Basically booms (floating barriers across the river), receptacles (containers that hold back debris) and watercraft vehicles (buoyant structures travelling on the water) can be distinguished. Many of the 40 evaluated devices, however, build synergies between these types. Based on the findings from the PlasticFreeDanube project and with respect to the available technical solutions as well as the boundary conditions of the project reach, suitable technical solutions shall be indicated below.

3.2.1. Floating Boom/trash boom

A tracer study carried out in the PlasticFreeDanube project revealed, that floating macro plastic tends to gather at the right river bank (green path) directly at the grate of the HPP Freudenau for discharges below 3000 m³/s as shown in Figure 3. At this location plastic is taken out in front of the grate as indicated by the blue cross. However, above from 3000 m³/s the weirs of the hydro power plat are overflown, leading to redirection of floating items towards the weirs. As the tracer experiment showed, in this way it is possible for macro plastic to pass the hydro power plant. Possible actions to prevent floating items from passing the barrier in this way are floating booms as indicated in yellow in Figure 3 right and described e.g. by AlphaMERS Ltd. (2020), Plastic Fischer (2020) or The Litterboom Project 2020). Further possible positions for thrash booms can be at tributaries to prevent macro plastic input from the catchment.

Figure 3 left: positions tracked with GPS- tagged floating macro plastic items, right: sketch describing the possibilities for the installation of a floating macro plastic barrier at the HPP Freudenau

3.2.2. Litter traps

Other technical solutions towards out macro plastic of a river system are litter traps as described by Clear Rivers (2020) or Elastec (2020). These boom-receptacle synergistic devices often have booms that guide debris into a receptacle where they remain trapped. Booms may also serve as a guidance for separate devices like the trash wheel (Waterfront Partnership of Baltimore, 2019) or the Inceptor (The Ocean Cleanup, 2020). Both systems represent anchored, autonomous devices with a conveyor-belt for debris removal. Boom-receptacle devices are a convenient way to remove plastics from the device and allow for simple measurement (Helsinki et al., 2021).

The numerical modelling results as well as findings from field studys derived within the project can serve as a basis to define most suitable positions for boom-receptacle synergistic devices like litter traps. As earlier described and shown in Figure 4, macro plastic shows the highest accumulation tendency in centre groyne fields. Therefore, these locations should be addressed, when implementing litter trapping devices. Besides groyne fields, also at the confluences from tributaries an installation of such devices can reduce the input of macro plastic.

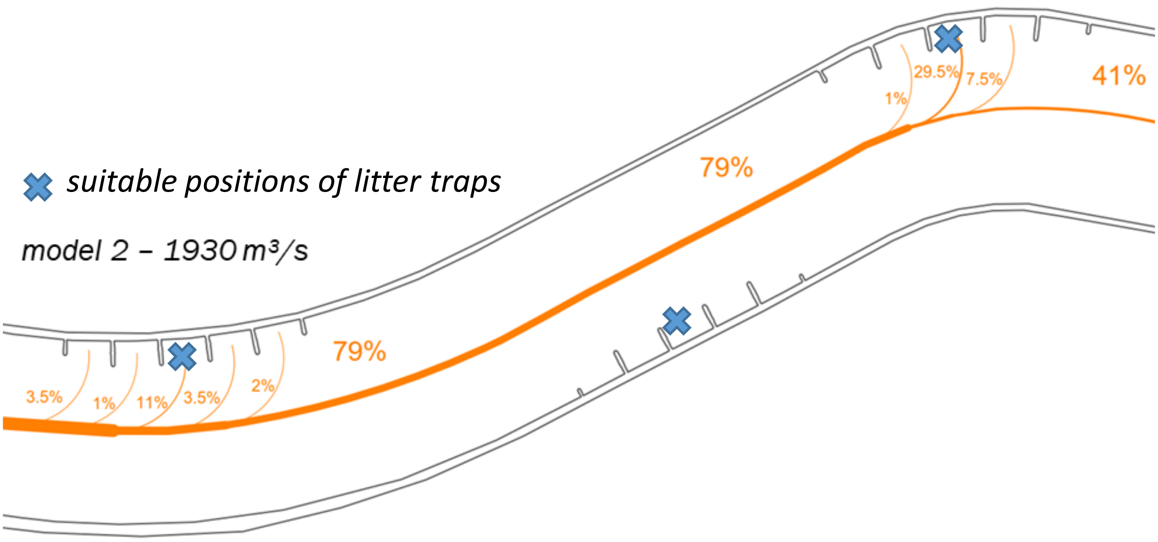

Figure 4 Suitable positions for boom-receptacle synergistic devices (blue crosses) based on results from numerical modelling and field studies

3.3. Maintenance measures

Besides the presented structural and technical solutions to reduce macro plastic in riverine environments, the findings within the PlasticFreeDanube project revealed several opportunities of non-structural maintenance measures. Suggested measures are presented below.

3.3.1. Bank-near sampling areas

An analysis combining numerical modelling results and long-term hydrological data revealed, that bank-near accumulations tend to occur at the most frequent water levels and can be can be separated in a spring/summer and an autumn/winter period (Figure 5). Based on these findings, the designated areas of potential macro plastic accumulation can be used to improve sampling actions targeting the bank-near zone.

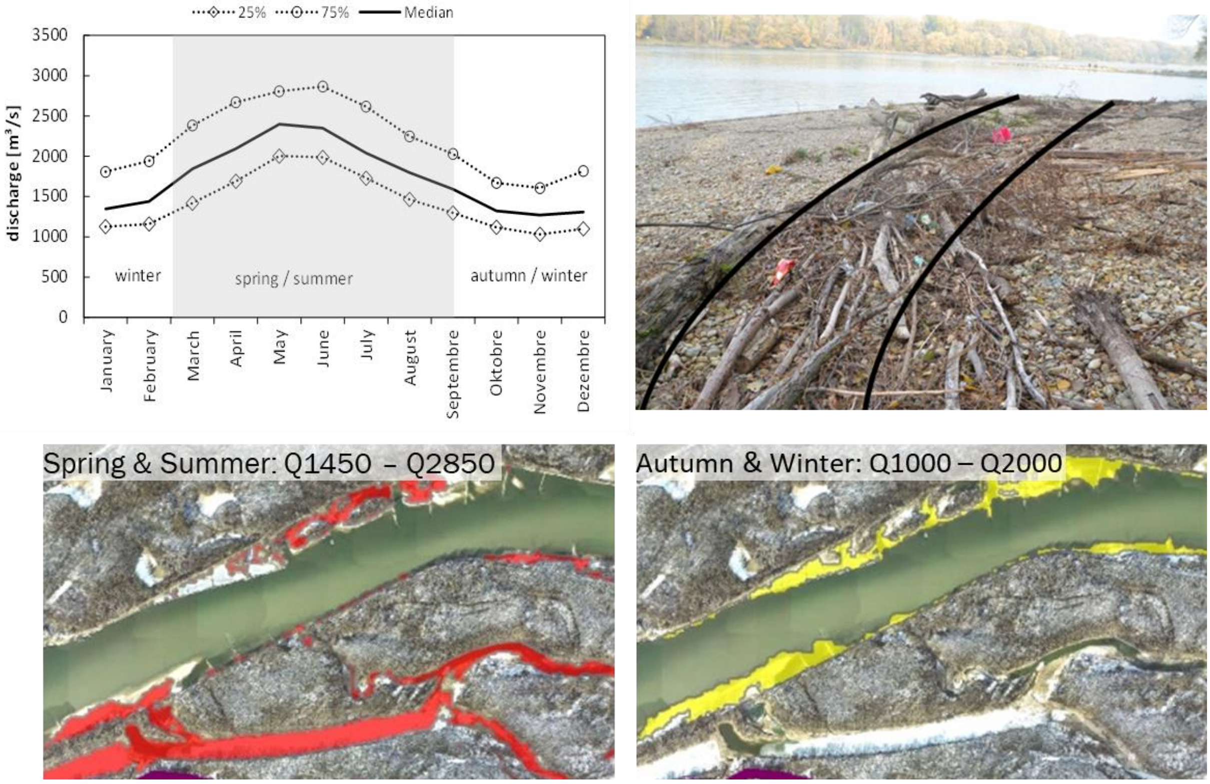

Figure 5 Bank-near accumulation at the Danube River - upper left: statistical discharge analysis, upper right: frequently founf shore line accumulation, lower left: determined area during spring/summer period, lower right: determined area during autumn/winter period

3.3.2. Hydrology — planning of cleaning activities at falling limbs

Besides the designated areas provided in chapter 3.3.1, respect should be given to the hydrology for the planning of sampling actions along a river system. Figure 6 provides an example of the hydrograph between 2 sampling actions. Green sections in the timeline were determined as periods with descending water levels, excluding remobilisation between smaller discharge peeks. For improved bank-near sampling, days with low water levels are suggested in order to maximize the sampled amounts of plastic and avoid remobilization.

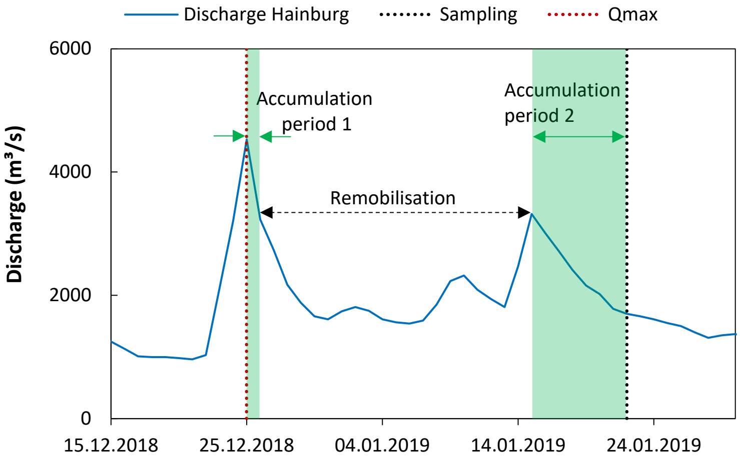

Figure 6 Determination of days with descending water level between two bank-near macro plastic samplings

3.3.3. Floodplain sampling areas

Site visits, samplings as well as numerical modelling results furthermore revealed, that areas of flow diversion from the Danube into the side channel system are characterized by a high accumulations potential (see Figure 7). In these sections, where plastic enters the side channel, high amounts of plastic deposit, often related to dense vegetation was found in the floodplain area. Accumulations were moreover found at various spots with woody debris (see Figure 8). These often-found characteristic elements of side channel systems build a natural barrier for macro plastic entering the floodplain. Therefore, during maintenance measures like sampling, a special focus should be given to these areas.

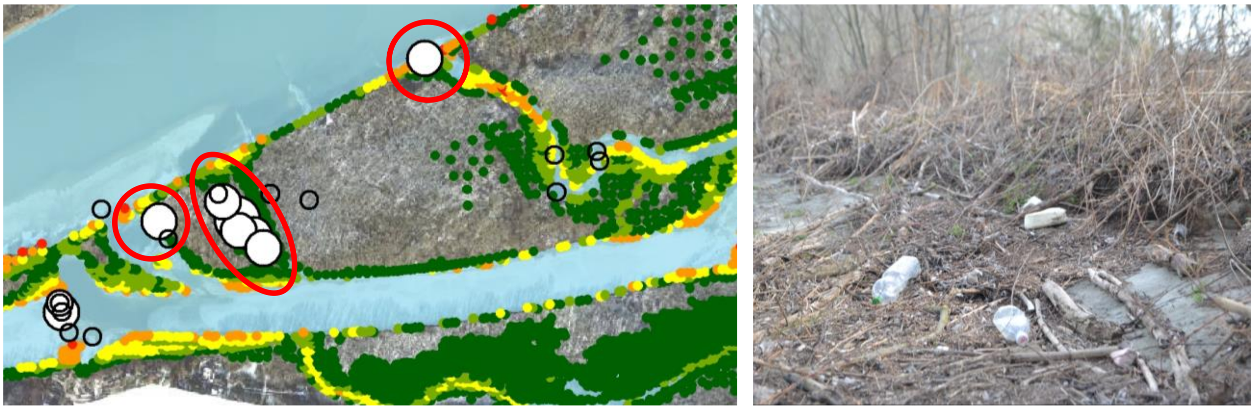

Figure 7 Macro plastic accumulations in the inflow sections to the side channel system Haslau-Regelsbrunn

Figure 8 Macro plastic accumulations related to woody debris in the side channel system Haslau-Regelsbrunn

4. Directories

4.1. List of figures

5. References

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