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WWTP and Debris: Summary of Studies

This piece helped inform a National Park Service research study on wastewater treatment plants (WWTP) as sources of microplastic pollution in the marine environment. I also repackaged it as a call-to-action style post on the official NOAA Marine Debris Blog.

Separate and Combined Sewer System Comparison

Sewer systems have traditionally followed two designs, combined and separate. In combined systems, dry weather flow, including domestic and industrial sewage, is channeled to the WWTP with wet weather flow. These systems can fail during heavy rains when the mixed streams overwhelm the plant, as a combined sewer overflow will discharge untreated wastes. Separate systems move the two flows in different networks, which reduces the risk of unhygienic discharge (Figure 1; Mannina & Gaspare 2009, 555-556). They have become standard in developed nations, (Brombach et al. 2005, 119) though many communities still use combined: in 2007, De Toffol et al. estimated that this design made up 70% of central Europe's sewer systems (255) and the EPA notes that around 40 million Americans, most in the Great Lakes and Northeast regions, depend on this model ("Combined" 2016). Many of these systems have been updated with larger tanks to minimize overflow. Though the separate design has become more popular, its merit over updated combined models has been debated (Brombach et al. 2005, 119).

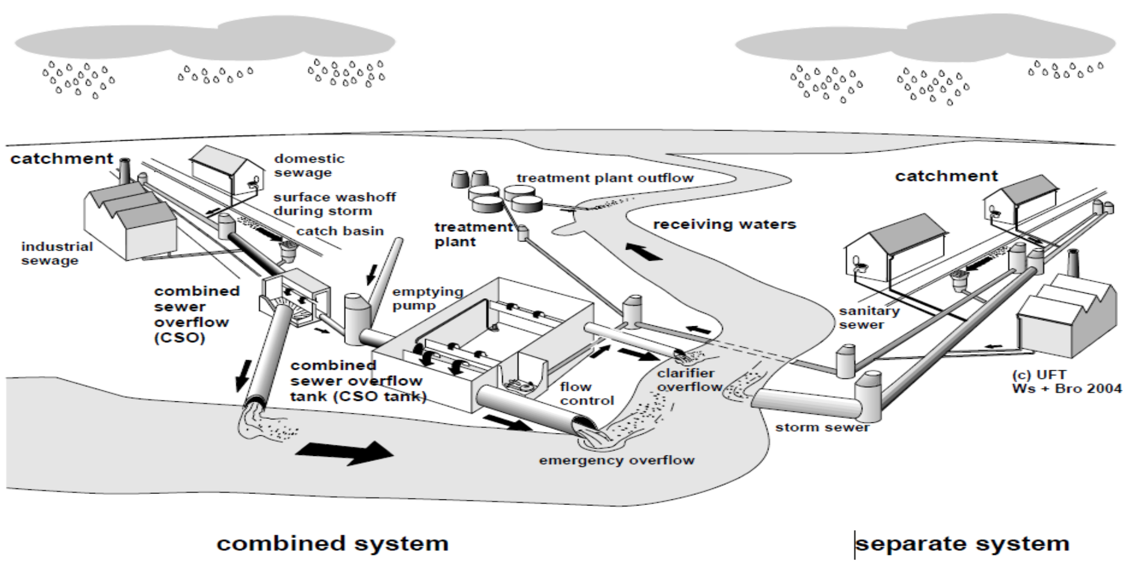

Figure 1. Traditional combined (left) and separate (right) sewer systems.

(Brombach et al. 2005, 120)

Several studies have compared separate and combined system function and efficacy:

- Brombach et al. (2005) compared German combined and separate systems on pollution load balance. The authors note that separate systems often lack rainwater treatment tanks, as storm runoff is assumed to be relatively clean. This study finds that separate systems are only advantageous for removing some pollutants, such as nutrients, while the combined system performs better with degradable materials and heavy metals. It also finds that the WWTP itself is important when evaluating a sewer system, as a better plant may favor the combined model. The authors recommend choosing a design based on local demands and pollutants, rather than generally preferring separate systems (119, 127-128).

- Mannina and Gaspare (2009) uses modelling to simulate combined and separate sewer systems under different rain conditions. They find that separate systems without stormwater treatment can discharge significant pollutant loads and better treatment tanks are necessary in either setup. The authors conclude that system choice should be done on a case-by-case basis (555, 564).

- De Toffol et al. (2007) compares separate and combined systems on ecological and economical performance indicators using case simulation. Without additional storm water treatment, they found separate systems can underperform, especially when accumulative pollution occurs. The authors conclude that low pollutant concentrations result in similar system performance, but higher may make combined systems preferable. They recommend considering local pollutant loads, rain patterns, and receiving water sensitivity when choosing a system (255, 260, 261, 263).

Based on these findings, separate systems without storm water treatment may release more microplastics than combined if their area has a large amount available to enter the wet weather network. Particles emitted through household uses, such as face washes and toothpaste, would be treated through WWTP either way.

Function of Wastewater Treatment Plants

A common schematic guides municipal WWTP design, though minor configuration differences may exist between facilities (Figure 2; Mason et al. 2016). Sewage moves through the following processing stages:

1. Preliminary Treatment: removes grit and large materials to reduce waste abrasiveness, clogging, and settling; screening with 6mm or larger mesh is used for removal; grinders are rarely used in newer systems (Mason et al. 2016, 2; WIDNR 2011, 12).

2. Primary Treatment: often uses clarifiers to capture floatable material, like grease and oil, and settle solids; both are directly removed before primary effluent advances (WIDNR 2011, 13).

3. Secondary Treatment and Final Clarification: microorganisms remove dissolved and suspended organic wastewater material in aeration tanks or pond and lagoon systems; settling tanks with clarifiers remove remaining solids from effluent (Mason et al. 2016, 2; WIDNR 2011, 13-14 and 16).

4. Advanced (Tertiary) Treatment: optional, depending on local regulations, physical or chemical processes that bring phosphorus, nitrogen, and suspended solids to low levels; effluent becomes high quality (Mason et al. 2016, 2; WIDNR 2011, 15).

5. Disinfection: final processing stage that kills illness causing microorganisms before discharge into local water body; methods include UV radiation units and chlorination tanks (WIDNR 2011, 16).

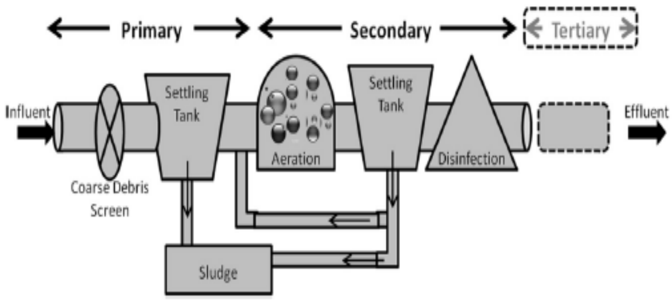

Figure 2: Schematic of a typical municipal facility indicating stages of processing. Tertiary treatment is optional and, if present, will vary between facilities. Coarse debris screening (identified here as part of primary treatment) can also be considered preliminary treatment (Mason et al. 2016, 2).

WWTP Impacts on Plastic Debris in Effluent

Plastic particles are a widespread contaminant of our oceans and waterways, with "more plastic in the ocean than fish by 2050" becoming an oft-quoted talking point (Kaplan 2016). Though their pathways to water bodies can vary, microplastics popularity in industrial and domestic products, from molding powders to face wash, have made municipal wastewater and WWTPs a suspected source (Mason et al. 2016, 1-2). Many recent studies have explored this connection, including:

- Baldwin et al. (2016) examines plastics in the Great Lakes watershed and finds a positive correlation between urban attributes, including wastewater effluent, and many debris types. WWTP specific influence varied across their study sites, from being 0 to 89% of stream flow, and they found little correlation between it and debris: larger plastics were washed in through storm sewer systems directly and microfibers may enter via agricultural runoff when WWTP sludge is used for fertilizer, but the plants' direct contribution was low (A-B, E-G).

- Carr et al. (2016) investigates effluent from seven WWTPs with tertiary treatment and one without in Southern California. The authors find that existing treatments are effective at removing plastics, as the majority was filtered out in primary phases and secondary treatment alone showed 99.9% efficiency. Tertiary treatments were effective at removing even more particles. They noted that consumer product microplastics made up the majority in WWTP effluent (174,181).

- In "Discharging Microbeads to Our Waters" (2015), the New York Office of the Attorney General examines the relationship between plastic microbeads and WWTP effluent. Despite only considering easily identifiable consumer product beads, the researchers find that most of their study facilities, 25 out of 34, discharge these pollutants after tertiary treatment. They conclude that current waste processes are ineffective for microbeads and that prevention is the best solution (1, 9).

- Magnusson and Fredrik (2014) evaluates Swedish WWTPs as microplastic sources to the marine environment. The authors find WWTP plastic retention is high, over 99%, but that the amount being discharged could still have impacts. They also note that temporal variations in plastic output and a lack of quantitative research on other plastic sources make estimating WWTPs' relative importance difficult. The authors remark on the lack of standard research procedures for mesh filter size and sludge handling as well (1, 17-18), which suggests methodological uncertainty.

- Martin and Eizhvertina (2014) analyzes microplastics in WWTP effluent in Canada's Niagara Region. It compares two WWTPs, one with mainly industrial input and one with more residential users, and finds plastics in the discharge of both, though the latter contributed much more synthetic fiber. They attribute this difference to domestic washing machine effluent, and recommend targeting this sector and personal care products for prevention efforts.

- Mason et al. (2016) reviews other studies and conducts a wide-ranging US effluent contamination survey. The authors find that, on average, treated wastewater contains less than 1 particle per liter. Because these plants work through millions of liters a day, however, millions of plastic particles may be released in that time (1-2, 4). Other findings include:
    - No correlation between advanced treatment and microplastic discharge reduction (5-6).
    - WWTPs' relative importance as a microplastics source is uncertain (8).
    - A plant's plastic particle variety and abundance in effluent depend on many factors, so more research is necessary to gauge WWTP efficacy (7, 9).

- Mintenig et al. (2017) looks at microplastics in twelve German WWTPs' effluent and sewage sludge. The authors also acknowledge the risks of contaminating samples with plastic post-collection; everything from synthetic fibers in clothing to lab materials can shed microplastics into the research environment. Even as they find particles and fibers in all samples from the WWTPs, the researchers believe analysis, sampling, and purification methods need to be standardized to confirm their findings via replicates and comparisons with other studies. The authors note a difference in plastic retention among tertiary treatments as well: membrane reactors and gravity filters proved less effective than rolling pile filters (365, 370-371).

- Murphy et al. (2016) looks at the treatment stages within a WWTP to evaluate which processes are filtering out plastics. The authors find primary removal and settling treatments are the most effective in this regard, and that WWTPs with weaker primary methods can discharge more plastics. They note that future research should use site-specific approaches that identify a WWTP's unique practices and temporal variation in microplastic release to glean each treatment's efficacy (A, G-H).

These studies point to WWTP being a probable microplastics source, via effluent or late stage sludge runoff, though many variables create uncertainty as to the problem's extent.

Final Thoughts

To say WWTPs are microplastic sources without qualification is an oversimplification. From the local sewer system design to rainfall conditions, population density, and microplastic-containing product use, many outside variables factor into whether plastic is released in a plant's effluent. In the WWTP itself, one must evaluate everything from mesh size in the primary stage to the tertiary treatments employed. That several studies found plants are over 99% effective in filtering out plastics, despite not being designed for this pollutant, is impressive. That WWTP may still discharge millions of particles a day, however, is troubling. Researchers themselves are also struggling with studying this problem.

Several researchers pointed to their own limitations in investigating the WWTP-debris connection: natural variations in rainfall and wastewater flow occur during study periods, outside plastic sources can contaminate samples, different processing techniques may degrade collected material, etc. Just as addressing this problem is a new frontier for WWTP, assessing it may be a new discipline for researchers. Standardizing research methodology may be the essential next step to quantify WWTPs as a microplastics source and work towards reducing their contribution.

WWTP Summary of Studies References

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Primary vs. Secondary Types of Wastewater Treatment - http://archive.epi.yale.edu/case-study/primary-vs-secondary-types-wastewater-treatment

Creative Primer, featuring differences: https://www.scientificamerican.com/article/treating-sewage/#

Philadelphia Combined System http://www.phillywatersheds.org/watershed_issues/stormwater_management/combined_sewer_system

Philadelphia Separate System: http://www.phillywatersheds.org/watershed_issues/stormwater_management/separate_sewer_system