water

IMPACT FACTOR 3.0

CITESCORE 6.0

Review

Research Status and Trends of Hydrodynamic Separation (HDS) for Stormwater Pollution Control: A Review

Yah Loo Wong, Yixiao Chen, Anurita Selvarajoo, Chung Lim Law and Fang Yenn Teo

MDPI

https://doi.org/10.3390/w17040498

water

MDPI

Review

Research Status and Trends of Hydrodynamic Separation (HDS) for Stormwater Pollution Control: A Review

Yah Loo Wong, Yixiao Chen, Anurita Selvarajoo, Chung Lim Law and Fang Yenn Teo *

Faculty of Science and Engineering, University of Nottingham Malaysia, Semenyih 43500, Selangor, Malaysia; evxyw17@nottingham.edu.my (Y.L.W.); evyyc4@nottingham.edu.my (Y.C.); anurita.selvarajoo@nottingham.edu.my (A.S.); chung-lim.law@nottingham.edu.my (C.L.L.)
* Correspondence: fangyenn.teo@nottingham.edu.my

Abstract: Growing urbanization has increased impermeable surfaces, raising and polluting stormwater runoff, and exacerbating the risk of urban flooding. Effective stormwater management is essential to curb sedimentation, minimize pollution, and mitigate urban flooding. This systematic literature review from the Web of Science and Scopus between January 2000 and June 2024 presents hydrodynamic separation (HDS) technologies. It sheds light on the significant issues that urban water management faces. HDS is classified into four categories: screening, filtration, settling, and flotation, based on the treatment mechanisms. The results show a shift from traditional standalone physical separations to multi-stage hybrid treatment processes with nature-based solutions. The great advantage of these approaches is that they combine different separation mechanisms and integrate ecological sustainability to manage urban stormwater better. The findings showed that future research will examine hybrid AI-assisted separation technologies, biochar-enhanced filtration, and green infrastructure systems. When adopting an integrated approach, the treatment system will perform like natural processes to remove pollutants effectively with better monitoring and controls. These technologies are intended to fill existing research voids, especially in removing biological contaminants and new pollutants (e.g., microplastics and pharmaceutical substances). In the long term, these technologies will help to enforce Sustainable Development Goals (SDGs) and orient urban areas in developing countries towards meeting the circular economy objective.

Keywords: stormwater treatment; separation Mechanisms; green infrastructure; stormwater treatment device; hydrodynamic separation (HDS)

check for updates

Academic Editor: Sajjad Ahmad

Received: 26 November 2024
Revised: 3 February 2025
Accepted: 6 February 2025
Published: 10 February 2025

Citation: Wong, Y.L.; Chen, Y.; Selvarajoo, A.; Law, C.L.; Teo, F.Y. Research Status and Trends of Hydrodynamic Separation (HDS) for Stormwater Pollution Control: A Review. *Water* **2025**, *17*, 498. https://doi.org/10.3390/w17040498

1. Introduction

The global trend of rapid urbanization has greatly converted naturally pervious surfaces into impermeable surfaces, escalating stormwater runoff and increasing the risk of urban flooding [1–3]. Stormwater runoff mobilizes pollutants that endanger both the environment and human health. Effective stormwater management is therefore crucial to manage sedimentation and alleviate urban flooding [4]. Under these circumstances, the transition towards water-sensitive cities has become an urgent priority [5].

The prevalence of man-made infrastructures and hardscapes has exacerbated stormwater pollution, disrupting natural hydrological processes and ecosystem services in urban areas [6,7]. Urban sprawl replaces natural covers with impervious surfaces, worsening runoff and degrading water quality [8]. Increased flooding risks and urbanization practices such as ground hardening and underground drainage networks exacerbate hydraulic hazards during rainfall events, significantly degrading surface and groundwater quality [9].

Polluted stormwater runoff also damages lakes, rivers, and coastal waters [10,11], especially in urban rivers [12,13]. Expanding concrete surfaces due to rapid urbanization necessitates alternative solutions, such as sustainable drainage systems (SuDSs) [14–16]. These systems have also shown promise in improving water quality [17].

Traditional drainage management strategies, such as trash screens for removing gross pollutants, are cost-effective but prone to clogging with plastic waste during heavy storms, creating additional obstructions [18,19]. While providing additional capacity for stormwater conveyance, open channels can act as conduits for pollutants like sediments, heavy metals, hydrocarbons, and nutrients, leading to downstream water quality degradation and endangering aquatic ecosystems [20,21]. Separate sewer systems, designed to handle stormwater runoff independently from sewage treatment plants, reduce the risk of system overload during heavy rainfall but still require additional treatment measures to address pollutants carried by runoff [22–24].

Stormwater management is gradually shifting towards holistic designs that utilize nature-based solutions (NbSs) and green infrastructure to address these challenges. These approaches integrate natural spaces into urban settings to restore ecological and hydrological quality while providing sustainable services like flood mitigation and water quality improvement [25,26]. Concepts such as water-sensitive urban design (WSUD), low-impact development (LID), and the Sponge City approach emphasize on-site stormwater treatment, ecological sustainability, and pollution reduction [27–32]. Combining LID practices with drainage retrofits and end-of-pipe treatments offers opportunities to enhance sustainability in urban planning [33,34].

Urban stormwater management is complex due to its non-point source origin and variable runoff quality, requiring collaborative efforts among governmental entities for education, enforcement, maintenance, and infrastructural integration [35]. Hydrodynamic vortex separation (HDVS) and green infrastructure offer promising solutions for contaminant removal while minimizing flood risks naturally [36].

This review systematically evaluates stormwater treatment technologies, focusing on physical treatment methods. It also provides a framework for evaluating stormwater treatments by examining design principles, operational performance, and applicability. This study explores how academia and the industry can align with Sustainable Development Goals (SDGs), particularly in advancing water-sensitive cities and a circular economy. Through a detailed examination of various hydrodynamic separation (HDS) technologies, ranging from conventional to advanced devices employing biochar, research gaps are highlighted. We provide guidance for policymakers, engineers, and urban planners in adopting adaptive strategies that mitigate urbanization's hydrological impacts while fostering long-term environmental and public health.

2. Materials and Methods

The systematic review exercise focuses on the role of HDS technology in stormwater control, covering the literature published between 2000 and 2024. The PRISMA framework was used to ensure the reporting quality and comprehensiveness. The literature was retrieved from Scopus and Web of Science using search terms such as "stormwater", "pollutant", "contaminant", and "separation technologies". The choice of Scopus and Web of Science for accessing peer-reviewed civil and environmental engineering literature is well-supported by their comprehensive coverage. A total of 206 papers were identified, with 40 duplicates removed. The other remaining papers were screened based on the criteria in Table 1. Only journal articles focusing on stormwater treatment were included, while conference proceedings, review articles, book chapters, and non-relevant publications were excluded. Only English-language journal articles were included to ensure consistency in data interpretation and align with the research scope, as English is the dominant language for scientific communication in civil and environmental engineering.

Table 1. The inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Publication type	Journal articles	Conference proceeding papers, review articles, book chapters
Language	English	Non-English
Water treatment	Relate to stormwater treatment	Not related to stormwater treatment
Period	Between 2000 and 2024	Earlier than 2000

Ultimately, 91 papers were used for analysis after exclusion criteria were applied. Figure 1 shows the overall process with number of removed articles for each screening stage.

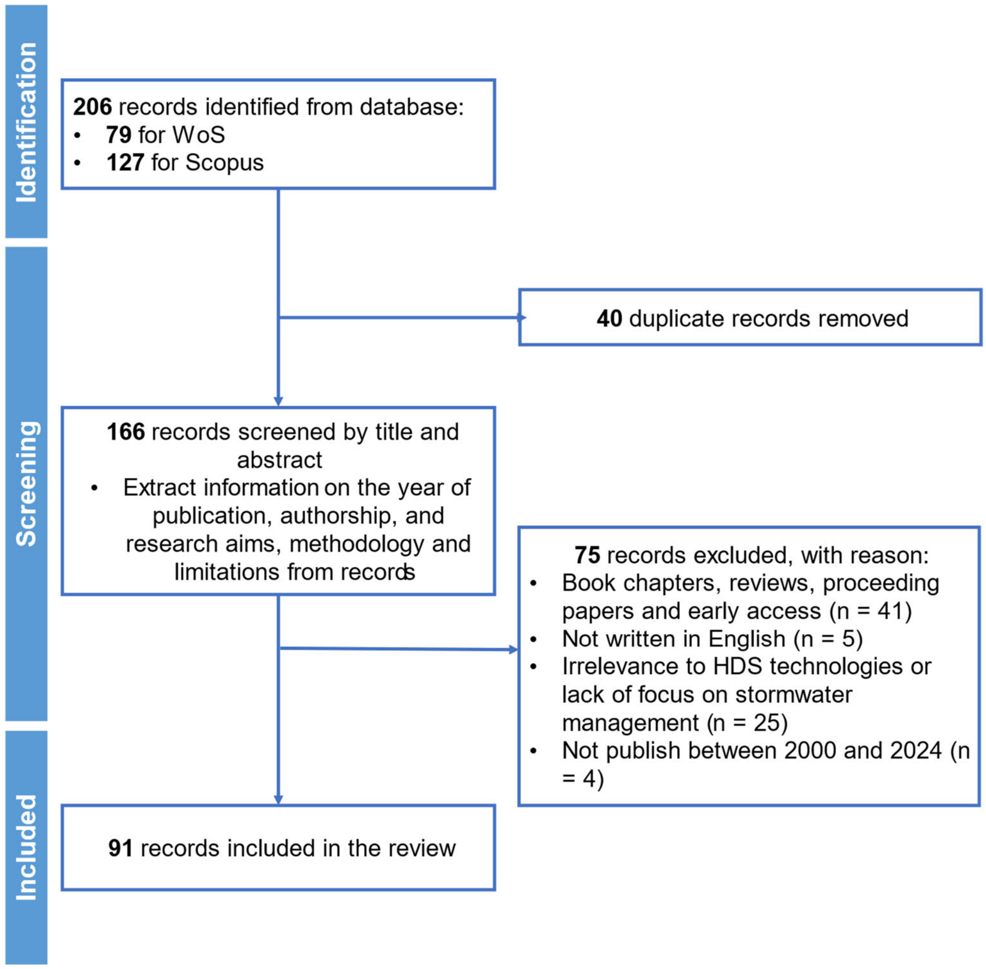

Figure 1. Flow diagram of overall process.

The data were collected using a data extraction form covering the year of publication, authorship, and research aims/methods of the included studies. The review focuses on water treatment and separation processes, particularly technologies like biochar combined with HDS processes. Research gaps are highlighted, along with connections between study findings and practical stormwater treatment technologies, such as gross pollutant traps (GPTs), screen systems, filtration devices, sedimentation/retention basins, and dissolved air flotation (DAF) technology. This approach delivers high-confidence insights into stormwater treatment.

3. Results and Discussion

3.1. Research Trends

Trends in the annual publications related to stormwater treatment from January 2000 until June 2024 are shown in Figure 2. Publication numbers might vary due to factors such as changes in funding opportunities, technological developments, and changes in environmental policies and concerns. At first, publications grew steadily, with interest in the area apparently on the up. This increase led to the largest number of publications in 2012, which could be interpreted as a peak year with respect to activity or awareness towards stormwater. At this time, it was reported that since 2009, Philadelphia, USA had used a sustainable approach to reduce its impervious surfaces by one-third, with the replacement surfaces controlling approximately 35% of the urban runoff [37]. China also introduced the "Sponge Cities" concept in 2012, which aims to enhance urban resilience through innovative water management strategies [38]. The peak in publishing was followed by a decline until 2022, after which publications began to rise again. This renewed interest could relate to the increasing frequency of extreme weather events and severe urban flooding, which have induced governments and research institutions to highlight this area of research [39].

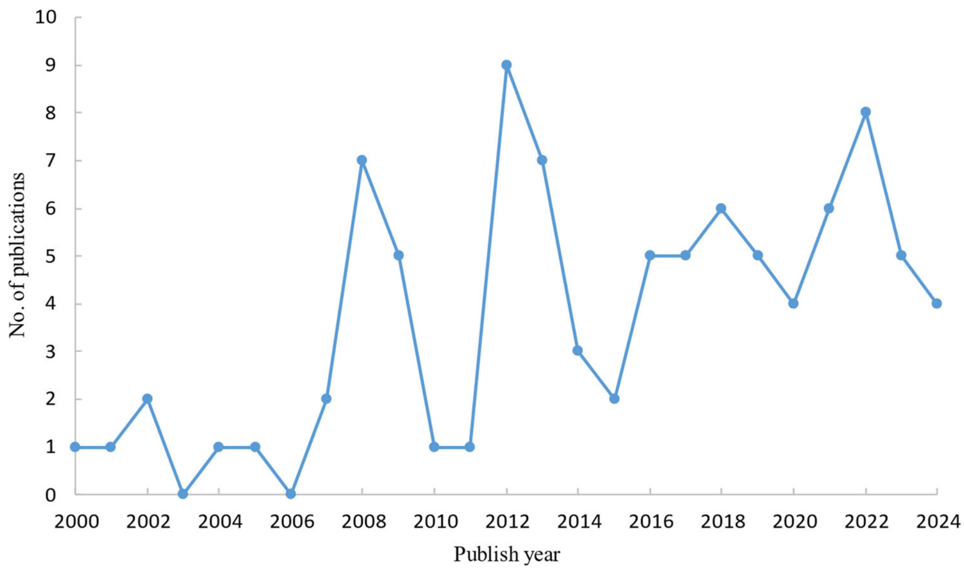

Figure 2. Time variation in the number of publications from 2000 to 2004.

Figure 3 shows the global distribution of publications. The USA leads with 27 publications, indicating a strong research foundation and high attention to this area. Australia follows with 12 publications, and China and Germany are close behind with 10 and 9 publications, respectively, which relates to their specific environmental challenges and urbanization issues, demanding advanced rainwater management techniques. Other mid-ranking countries, such as South Korea, France, and several Nordic nations, also show notable research activity. Although smaller countries like New Zealand, Brazil, Italy, the UK, Japan, Malaysia, Norway, and Serbia have fewer publications, their research contributes significantly to the development of global stormwater treatment technologies and strategies, highlighting the diverse research efforts and potential for international collaboration among different countries in addressing climate change and urbanization challenges.

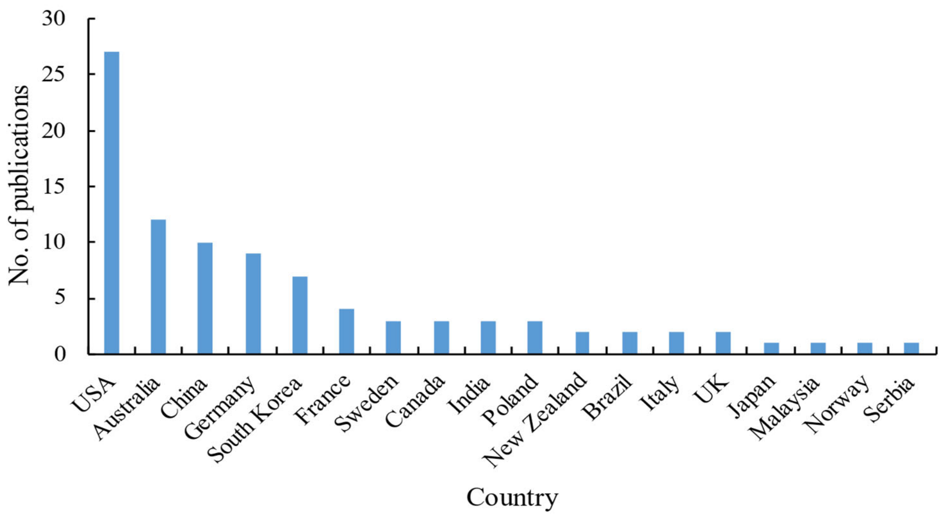

Figure 3. Geographical distribution of publications.

3.2. Stormwater Characteristics

Stormwater characteristics are influenced by factors like intense storm events, non-uniform runoff generation, the duration of precipitation, and antecedent dry days [40,41]. The quality of stormwater runoff can differ dramatically depending on the kind of surface it drains from. For instance, the specific pollutant concentrations associated with roof runoff are typically different from those for road runoff—the latter is more likely to contain contaminants from vehicular emissions and if it enters soil/water bodies directly, an informally higher total load can be carried in a particular volume of flow [42]. This variability makes stormwater runoff a challenging environmental problem.

The "first flush" effect is a common phenomenon in stormwater runoff, where the initial flow carries the highest concentration of pollutants previously deposited on surfaces into water bodies [43,44]. It is followed by a second phase often called the "middle flush", "end flush", or "2nd wave", which involves the mobilization of less mobile contaminants [45]. This pattern is commonly observed in urban catchments [46]. The upstream drainage contamination severely damages the bodies of water that receive this flow. The detection of urban wastewater in China has reflected that environmental pollution is also an issue seriously interconnected with public health [47,48]. These pollutants are mobilized during subsequent rainfall periods and eventually adversely impact surface water quality (SWQ) and shallow groundwater accumulation on surfaces over long dry intervals [42,49]. More than 60% of pollutants from non-point sources contain suspended solids, organic pollutants, and nutrients [50].

Stormwater quality is assessed based on physical, chemical, and biological parameters. The Water Quality Index (WQI) is a broadly used public information tool for summarizing the overall water quality with the help of multiple parameters. The biochemical oxygen demand (BOD) is one of the factors used in WQI assessment and reflects the water-dissolved oxygen utilized by aerobic micro-organisms. High BOD levels lead to excessive oxygen depletion, and hence stressful conditions for aquatic life; moreover, the odor of sewage can be perceptible during such events [51]. Ammoniacal nitrogen (AN) is composed of ammonia NH_3 and ammonium NH_4^+ and offers a nutritional element for plants; however, it can cause toxicity in aquatic organisms at high levels. The pH and temperature conditions affect the AN concentration in a wastewater treatment plant [42,52,53]. Total suspended solids (TSSs) are solid particles suspended in water, which can lead to a significant deterioration of the water quality [50]. TSS concentrations usually peak during heavy rainfall and differ significantly between small and large storms [54]. Elevated concentrations of

TSSs can cause aesthetic problems and also may have adverse effects on the aquatic environment, such as a reduced penetration of sunlight into the water column and an increase in temperature [40,42,54].

Figure 4 displays the focus on various pollutant types, as documented in scholarly works from 2000 to 2024. It illustrates that there has been a sustained and heightened interest in suspended solid particles throughout this period. Among the suspended particles, fine PM (<75 µm) accounted for the majority, followed by gravel-sized PM (>2000 µm) [55]. Organic pollutants and metals are also significant, albeit with a slightly lesser research focus than suspended solids [56–59]. The scrutiny of nutrients escalated in 2008, potentially caused by the increased use of fertilizers and the recognition of automotive and road maintenance products as their predominant sources [60,61]. Additionally, in urban landscapes where stormwater and sanitary sewage are channeled through combined sewer systems, the risk of system overload during substantial rain events is high [62]. It can result in overflows where untreated sewage and stormwater are discharged into the environment [53,63]. Thus, biological pollutants, including E. coli, have drawn considerable research attention from sewer flow [64]. The escalating usage of plastics has contributed to a substantial boost in microplastic research since 2020. Such particles are mostly found in industrial and commercial areas, with much lower levels in agricultural landscapes [65,66].

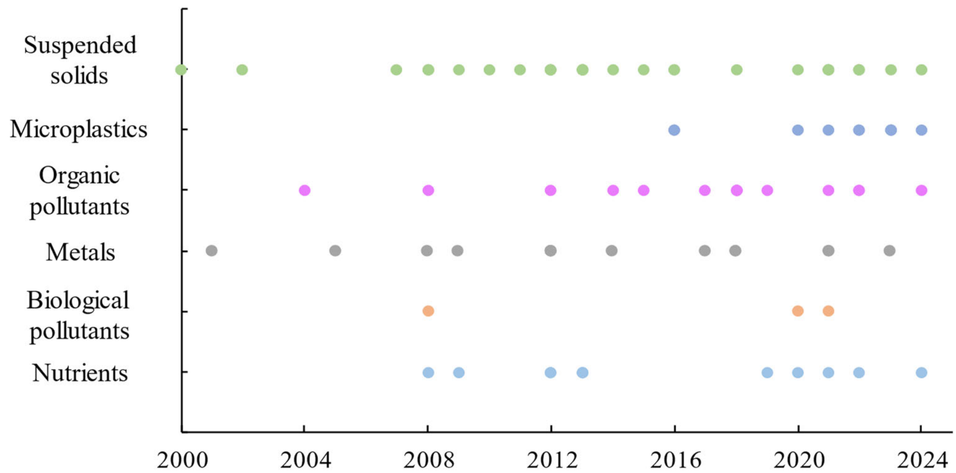

Figure 4. Time variation in the publications on different types of pollutants (indicates with different colors).

Stormwater is a complex and variable mixture, so it can be challenging to appreciate how stormwater behaves. The compositional complexity of urban stormwater, its distinct contamination characteristics, and important water quality parameters reveal the necessity of localized solutions to combat environmental threats from stormwater.

3.3. Stormwater Separation Technology

Stormwater treatment processes are not as stringent as drinking water processes, mostly due to the purpose of stormwater reuse and the types of contaminants they treat. Drinking water treatment is a process where water is treated according to public health and universally accepted standards that aim to destroy pathogens and chemical contaminants, to make it safe for human consumption; meanwhile, stormwater treatment manages runoff in areas where pollutants may contain sediments, nutrients, or pathogens, but those are not necessarily removed according to a fully regulated industry protocol [29,40]. In Malaysia, it is often considered as greywater or sullage-water [67]. This is a kind of water mixed with surface sewer, oil and grease, urban contaminants such as chemicals, microplastics, pharmaceutical residues, and many others [53,68].

Stormwater treatment is an essential process worldwide to treat stormwater runoff pollutants before they rush into natural waters. Generally, this process includes the use of various physical, chemical, and biological methods that help to filter, purify, or treat polluted water [69–71]. Stormwater treatment systems comprise wide arrays of pollution-capturing devices from GPTs of direct screening types, to trash screens designed to capture larger debris and pollutants, and the HDVS type for water quality treatment such as continuous deflective separation (CDS). The common objective is to reduce the amount of gross pollutants that will ultimately enter downstream water bodies [72–74]. To simultaneously decrease the risk of damage to sewage treatment plants, separate sewer systems and dedicated stormwater treatment systems, such as hydrodynamic separators and retention basins [75,76], have been adopted. These systems help divert stormwater away from sewage treatment plants, preventing overload and ensuring more efficient treatment of both stormwater and sewage [77].

In current stormwater treatment, the classification schemes for treatment systems focus on different aspects, namely, the treatment mechanism or the level and target pollutants to be removed. Quigley (2005) used the idea of classifying the unit process and operations (UOPs) from the wastewater treatment field, allowing processes to be combinations of biological and chemical operations while separating them by their physical states [78]. However, such operations were subsequently given quite different names: "a distinction was soon drawn at least between physical processes and others", but this became too narrow "because many processes in physics develop chemical attributes, etc." Minton (2007) provided a detailed classification in five families, based on key characteristics of the treatment mechanism at one end of the spectrum, and at another end, with a proposed five-level hierarchy based on key features [79]. Minton (2007) also proposed another new classification grouped by common design criteria, into five families: Basins, Swales, Filters, Infiltrators, and Screens.

The classification was further improved by Shrestha and Brodie (2011) [80]. The treatment system devices (TSDs) are classified as size separation and density separation based on the treatment mechanism. Density separation relies on gravity for settling solids, while size separation uses barriers to capture oversized solids. The first type utilizes the force of gravity to cause particles to settle in a liquid, whilst the second uses gaps formed with various barriers installed on screens. Each of the sub-themes are presented in Figure 5. These pre-treatment systems are not only used in industrial plants to manage stormwater contaminated with specific pollutants but are also being adapted for urban stormwater management.

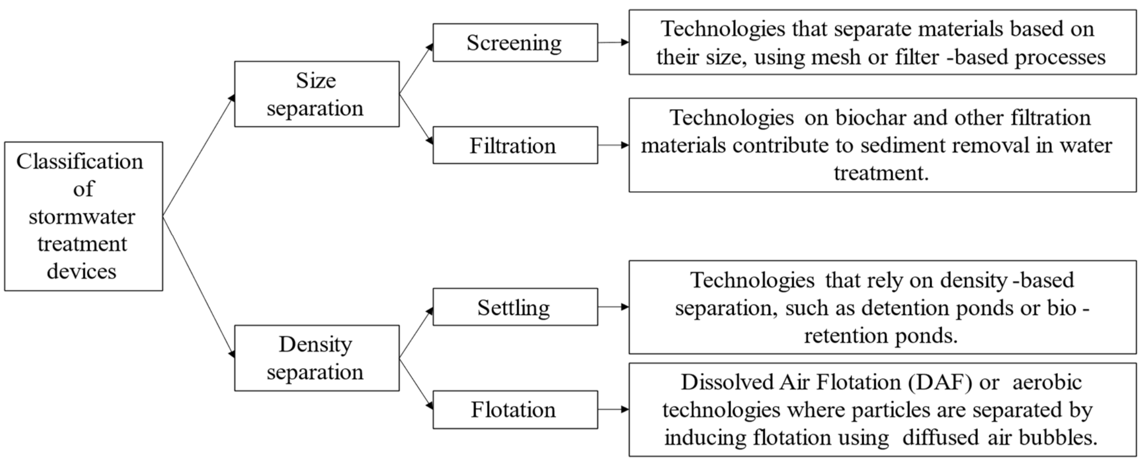

Figure 5. Classification of stormwater treatment devices.

The distribution of publications by separation type is illustrated in Figure 6. Filtration-based stormwater separation techniques are most commonly featured, representing 43% of publications, indicating their widespread application in this emerging field, followed by settling, which accounts for 35%. Flotation is documented in 13% of the publications, showing it as a recognized, albeit less researched method compared to filtration or sedimentation. Screening is explored less frequently, appearing in 7% of publications. In the existing studies, 11% of publications focused on multi-mechanistic treatment devices, suggesting new directions for integrating diverse separation technologies to enhance pollutant removal from urban stormwater.

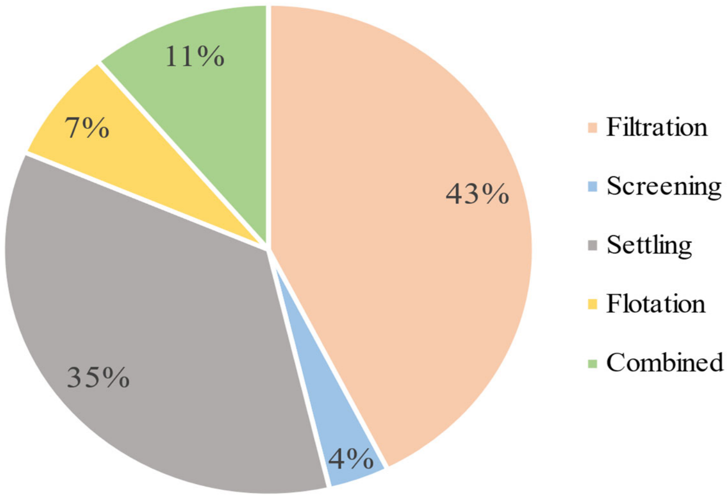

Figure 6. Percentage of publications for each type of separation.

3.3.1. Density Separation

Density separation technologies can be divided into two sub-themes: settling and flotation. These will be further detailed below.

Settling

Settling refers to the gravitational process by which particles with a density greater than that of water settle at the bottom [81,82]. This process often involves detention pools or ponds and HDS systems, as outlined in Table 2. Unlike retention reservoirs intended for flood mitigation, a detention pool is a kind of urban stormwater treatment system that allows particles to settle over extended periods, with large cost variations depending on the size, design, and location [83]. HDS systems can be retrofitted into underground drainage systems and integrated with multiple physical processes [84]. Performance is heavily influenced by particle distribution, density, and fluid temperature [85].

Detention pools are traditional approaches for stormwater treatment, effective in removing large and medium suspended solids [86] and microplastics [66,87]. Incorporating features like two-stage facilities and multi-level outlets can significantly enhance efficiency in removing suspended particles [88]. Brooks et al. (2023) suggest that microplastics with regular shapes can be effectively removed through settling in stormwater ponds [87]. Iannuzzi et al. (2024) further demonstrate that the settling process can capture microplastics ranging from 50 to 500 μm [66]. However, Fassman (2012) noted that detention basins are less effective in removing dissolved metallic pollutants [83].

To overcome the drawbacks of conventional detention ponds, achieving a high hydraulic efficiency for solid separation from stormwater and sewage has been the driving force behind the development of HDS systems [89,90]. This innovation brings a better approach for pollutant control from stormwater. Although these devices achieved removal efficiencies between 8.54 and 43.69% for particles >75 µm [91], they struggle with smaller particles, which dominate urban runoff [92]. On the other hand, using centrifugal forces affords HDVS systems better capabilities for suspended particle removal [93,94], which can enhance the removal of suspended solids and related pollutants. HDVS systems' efficiencies are based on the flow rate, particle size, and type of separator employed. Studies show a marked decrease in TSSs and other contaminants that greatly enhance the WQI [84,95]. They have highlighted the suspended solid, hydrocarbon, and nutrient removal capabilities of these systems. The majority of the available studies confirmed the presence of fine particles (60 µm particles), whose removal efficiencies were around 70% [96]. Furthermore, it has been reported that installing inlet baffles enhances the particle removal efficiency by 5–10% [97]. HDVS systems are an integral component in safeguarding receiving waters and promoting ongoing urban water management practices by effectively removing sediments and pollutants. However, as the settling process relies on gravity to separate the particles, it normally requires a long time for fine particles to settle, which reduces the efficiency and highlights the need to incorporate other types of treatments [85,88,98].

Table 2. Summary of settling separation.

Publication	Study Region	Method	Device	Pollutant	Remarks
[99]	Australia	Laboratory experiment	Cylindrical pollutant trap	Suspended particles and oil	Device is effective in separating fine particles but less so for suspended oils.
[90]	South Korea	Field study	HDS	Suspended particles	Single large device provides a better performance than multiple small devices in removing suspended particles.
[91]	South Korea	Laboratory experiment	HDS	Suspended particles	Device is effective in removing particles larger than 75 µm, with a removal efficiency of 8.54 to 43.69%.
[92]	USA	Laboratory experiment	HDS	Metals and bacteria	Device is not able to remove particles smaller than 75 µm, which are the most predominant particles in urban runoff.
[89]	USA	Model simulation	HDS	Sediment	Device is efficient in removing heavy particles.
[86]	USA	Field study	HDS and dry detention basin	Suspended particles	Device is able to remove large particles, but not small particles. Dry detention pool is able to remove large and medium particles.
[93]	USA	Model simulation	HDVS	Suspended particles	Device is effective in removing suspended solids.
[94]	China	Laboratory experiment	HDVS	Suspended particles	Device is effective in removing suspended particles.
[84]	South Korea	Model simulation	Hydrocyclone separator	Suspended particles and hydrocarbons	Device is effective in removing pollutants and nutrients.
[96]	France	Model simulation	Hydrocyclone separator	Organic matter, trace elements, hydrocarbons, and PAHs	Device is able to separate fine participles with a size of 60 µm, with a removal efficiency of 70%.
[97]	South Korea	Model simulation	Hydrocyclone separator with baffle	Suspended particles, hydrocarbons, and nutrients	Inlet baffle increases the device's particle removal efficiency by about 5–10%.
[100]	USA	Laboratory experiment	Mini-hydrocyclone separator	Microplastic	Device shows potential in separating microplastics in industry and urban stormwater systems.
[101]	China	Model simulation	Interception system overflows	NH3-N	Sewer separation can significantly reduce pollutant loads.

Table 2. *Cont.*

Publication	Study Region	Method	Device	Pollutant	Remarks
[85]	China	Laboratory experiment	Settling lab experiment	Suspended particles	Particle distribution has the largest impact on the settling performance, followed by density and fluid temperature. De-icing salt concentration and particle shape do not have an impact on the performance.
[98]	Germany	Laboratory experiment	Settling lab experiment	Suspended particles	Separation limit of 20 µm is sufficient for removing suspended particles.
[88]	Canada	Model simulation	Detention pool	Suspended particles	Two-stage facilities and multi-level outlet are important design elements in increasing the removal efficiency of suspended particles in dry ponds.
[83]	New Zealand	Model simulation	Detention basin	Suspended particles and dissolved zinc and copper	Poor removal efficiency of pollutants.
[66]	France	Field study	Detention basin	Microplastics	Microplastics with sizes of 50 to 500 µm can be removed through a settling process.
[87]	USA	Field study	Stormwater ponds	Microplastics	Settling can remove regular-shaped microplastics.

Flotation

Flotation involves the addition of air bubbles or defused air to stormwater to agglomerate the upward-floating fine particles into a foam or scum, which can be removed from the top of the tank. Table 3 summaries separation technologies on floatation.

DAF effectively removes suspended solids, oils, and other contaminants by introducing microbubbles that will attach to the particles and cause them to float, due to the difference in specific gravity to raise to the surface for removal [102,103]. The efficiency of DAF systems in separating particles mainly depends on the size and distribution of air bubbles [104]. Other flotation-based treatment devices have also performed well in removing oils from stormwater. Velautham et al. (2022) found that a corrugated plate interceptor (CPI) is particularly effective at separating and removing oil from stormwater [105]. Tarnowski et al. (2018) conducted a lab experiment with a separator designed for biofuel, achieving an impressive 99% removal rate [106]. Tang et al. (2018) examined certain types of oil–grit separators (OGSs) and discovered they are highly efficient at removing oil and grit from road stormwater runoff, indicating their effectiveness in managing urban stormwater pollution [107]. The operation is more complex as it requires air injection and mixing, along with precise control of the bubble size to sustain the high removal efficiency [103,105,107].

Table 3. Summary of flotation separation.

Publication	Study Region	Method	Device	Pollutant	Remarks
[105]	Malaysia	Field study	CPI	Oil–grit	CPI can effectively separate and remove oil from stormwater in airports.
[106]	Poland	Laboratory experiment	Separator lab experiment	Biofuel	Device is able to remove 99% of biofuel.
[103]	USA	Laboratory experiment	DAF	Suspended solid	DAF can efficiently remove the suspended solids of the drainage.
[107]	Canada	Field study	OGSs	Oil–grit	Device is efficient in removing oil and grit from road stormwater runoff.

3.3.2. Size Separation

Size separation technologies can be divided into two sub-themes: filtration and screening. These will be further detailed herein.

Filtration

These results offer a thorough summary of the performance of infiltration and filtration systems treating urban runoff as summarized in Table 4. Stormwater infiltration has considerable potential to treat combined sewer overflows, as illustrated in a study by Peter et al. (2007) [108]. Gevaert et al. (2012) emphasized the need to reduce the risk of organic pollutant emissions to the environment and therefore improve river quality [109]. Microplastics are integrated into pavement materials and thus specific filtration systems, to effectively control surface runoff and suspended particles [110,111].

Wetland systems play an important role in preventing the flow of nitrogenous and biological contaminants, such as *E. coli* [112,113]. The potential of modifier and traditional bioretention soil mixtures (BSMs) in bioretention media for nitrogen pollutant removal has been demonstrated [114]. But they tend to raise the water table during recharge, and this can damage underground infrastructure as well as generally disturb the urban water cycle [115]. Additionally, retention soil filters can remove pharmaceutical pollutants from combined sewer overflows [116].

Research on the efficacy of various filter media for contaminant removal from stormwater reveals diverse capacities. Filters incorporating hydrous ferric oxide have proven effective in capturing suspended particles and metals [117]. Ahmadi et al. (2018) demonstrated that Al-Mg/graphene oxide filters can remove many organic pollutants, including pharmaceutical chemicals [118]. Filters constructed with various media have shown high removal rates for metals such as lead, copper, cadmium, and zinc from stormwater [119,120]. Murray and Örmeci (2020) found that microplastics larger than 0.22 μm could be effectively removed using filters, although smaller particles may still elude filtration, suggesting the need for improved filtration technologies [121]. Zhou (2024) reported that synthetic loess-loaded silica gel filters can effectively remove nitrogen and phosphorus, including ammonium and nitrate [122]. Ataguba and Brink (2022) compared different filter media for oil and grease removal, identifying the granular activated carbon–rice husk (GAC–RH) filter system as the most efficient, thereby underscoring the potential for cost-effective solutions in hydrocarbon pollution control in stormwater treatment [123]. Regular maintenance is required to replace the mixture, to maintain the performance in removing pollutants from stormwater, which may potentially increase the operation cost [117,124,125].

Table 4. Summary of filtration separation.

Publication	Study Region	Method	Device	Pollutant	Remarks
[108]	Germany	Model simulation	Stormwater infiltration	Sewerage	Infiltration has potential in the treatment of combined sewer overflows.
[109]	Germany	Model simulation	Road and drainage infiltration	Di (2-ethylhexyl) phthalate (DEHP)	Reducing pollutants released into the environment is considered a best practice in improving the river quality when compared with modification of the infiltration process.
[110]	USA	Field study	Using microplastics as pavement material improving infiltration	Metal	It can offer a solution to the pollution of surface runoff.

Table 4. *Cont.*

Publication	Study Region	Method	Device	Pollutant	Remarks
[111]	USA and Italy	Field study	Pavement filtration system: a bituminous-pavement, open-graded friction course (BPFC) and an aggregate-filled infiltration trench	Suspended particles	Devices are able to reduce the environmental impact.
[112]	USA	Laboratory experiment	Wetland	Biological pollutants	Wetlands help prevent climate-related migration of *E. coli* to the shore.
[113]	South Korea	Laboratory experiment	Wetland	Nitrogen	Wetlands perform effectively in removing nitrogen pollutants.
[83]	New Zealand	Model simulation	Wetland, bioretention, and permeable pavement	Suspended Solids and dissolved zinc and copper	All approaches meet the discharge criteria for suspended solid and zinc; however, they do not perform well in removing copper. Permeable pavement can prevent 2/3 of the pollutants from urban stormwater.
[115]	USA	Model simulation	Bioretention basin	-	Bioretention basin recharge has the potential to raise the water table, which has negative impacts on the underground infrastructure and urban water cycle.
[114]	China	Laboratory experiment	Bioretention media comprised a mixture of modifiers and traditional BSM	Phosphorus	Green zeolite, fly ash, vermiculite, and turfy perform well in removing nitrogen pollutants.
[65]	Australia	Field study	Conventional and activated sludge (AS) lagoon system	Microplastics	This is a low-energy, low-cost, and effective water treatment measure for removing MPs.
[116]	China	Field study	Retention soil filter	Pharmaceutical pollutant	Retention soil filter is able to remove pharmaceutical concentrations from combined sewer overflow.
[126]	USA	Laboratory experiment	Filtration paper and nylon net	Suspended particles	Nylon net has a better performance in filtering particles smaller than 20 µm than filtration paper.
[117]	USA	Laboratory experiment	Filter with media of hydrous ferric oxide	Suspended particles and metal	Device is efficient in removing metallic pollutants.
[124]	India	Laboratory experiment	Filter with media comprising a mixture of gravel, coconut fiber, and sand	Sediment, NO, SO, suspended particles, Mg2+, and Na+	Device is efficient in removing pollutants and being economic at the same time.
[125]	Australia	Laboratory experiment	Filter with media of compost	Metal (Zn)	Particle size of compost impacts the filtration efficiency.
[119]	China	Field study	Filter with media of plain sand, granular activated carbon, and cementitious media to oxide-coated/admixture media (MOCM)	Metal (Pb, Cu, Cd, and Zn)	MOCM performs best in removing metals from stormwater runoff compared to other media.
[120]	Germany	Field study	Filter with media of granular activated carbon, a mixture of granular activated alumina and porous concrete, granular activated lignite, half-burnt dolomite, and two granular ferric hydroxides	Metal (Cd, Cu, Ni, Pb, and Zn)	Most of the media are able to filter Cu and Pb from stormwater.

Table 4. *Cont.*

Publication	Study Region	Method	Device	Pollutant	Remarks
[118]	USA	Field study	Filter with media of Al-Mg/GO	Phosphate, copper (II), and Diclofenac (DCF)	Al-Mg/GO showed a good performance in removing all three pollutants.
[127]	Norway	Laboratory experiment	Filter with media comprising a mixture of crushed clay and granular activated carbon	Organic de-icing chemicals	Achieved removal efficiency on DOC.
[123]	USA	Laboratory experiment	Filter with media of a low-cost, granular activated carbon–rice husk (GAC–RH) filter system, river gravel–granular activated carbon (GR–GAC) filter system, rice husk only (RH) filter system, and the conventional PVC O&G trap (COT)	Oil and grease	GAC-RH has the highest removal efficiency of oil and grease, followed by RH, GR-GA, and COT. More improvement is required for future research.
[122]	China	Laboratory experiment	Filter with media of synthetic loess-loaded silica gel (CSG)	Nitrogen and phosphorus	Filter is able to remove nitrogen and phosphorus and is more effective for the removal of ammonium and nitrate nitrogen.
[51]	Poland	Laboratory experiment	Rapid filtration on sand filters	Suspended particles, hydrocarbon, and biological pollutants	Rapid filtration on sand filters can remove hydrocarbon, nitrogen, and phosphorus.
[121]	Canada	Laboratory experiment	0.22 µm filter, centrifugation, and ballasted flocculation	Microplastics	Three treatments perform well in removing particles; however, smaller particles might escape and enter into the environment.

Screening

In stormwater screening, screen devices remove suspended solids by promoting the settling of these solids to the device floor. Sedimentation is a basic mechanism for particle capture used in many stormwater treatment systems that, although simple, provides cost-effective particulate removal capacity. Solid removal can be considered screening and is sometimes termed manual and mechanical [128]. It is often also referred to as the first step of categorizing waste types and producing documentation for further analysis, and so it is called classification. While exhaustive screening is the first step of separation treatment systems, it does not typically serve as a standalone process. Table 5 illustrates the relatively lower efficacy of devices employed with screening technology for the removal of <25 µm particles and *E. coli* from stormwater [64,129]. Hence, screening is often combined with other separation processes, which will be described in following sections.

Table 5. Summary of screening separation.

Publication	Study Region	Method	Device	Pollutant	Remarks
[129]	UK	Field study	Oil interceptors	Floatable impurities (leaves, oil) and total suspended solids	Interceptor achieves a removal efficiency of 70% for suspended solids; however, it is not able to separate particles smaller than 25 µm.
[64]	USA	Field study	Lab experiment	*E. coli*	Screening filtration is not able to reduce the concentration of *E. coli* from lab tests.

3.4. Combined Separation

As different separation technologies effectively treat specific pollutants, several studies have explored the potential for integrating multiple separation processes into a single system to address their limitations. Combining various technologies can efficiently remove a broad range of pollutants, resulting in optimized stormwater treatment systems, as illustrated in Table 6.

Table 6. Summary of combined separation.

Publication	Study Region	Method	Types of Separation	Device	Pollutant	Remarks
[130]	Australia	Field study	Settling and screening	CDS	Suspended solids and dissolved species	It can effectively remove suspended solids, as well as the particles smaller than the screen aperture, from stormwater.
[131]	Australia	Research study	Settling and screening	CDS	-	It can reduce several pollutants from raw sewage at high rates.
[132]	Australia	Laboratory experiment	Settling and screening	CDS	Suspended solids, metal, and nitrogen	It can efficiently remove suspended solids, Cr, Cu, Pb, Mn, and Fe from stormwater; however, it does not perform well in removing Ni, Zn, and nitrogen.
[133]	USA	Laboratory experiment	Settling and screening	SPLITT fractionation	Metal	SPLITT fractionation is capable of removing metallic pollutants smaller than 50 µm.
[134]	India	Model simulation	Settling and filtration	PGI	Suspended solids and nitrogen	PGI integrates a silt trap and biofilter. It is able to achieve removal efficiencies for suspended solids and phosphorus from 50 to 90%. However, it cannot replace the conventional wastewater treatment plant.
[135]	UK	Model simulation	Settling and floating	MPPS	Oil and heavy metal	MPPS consists of a floating mat interceptor and settling tank. The former is used to intercept oil and the latter is used for particle settling. It shows a high removal efficiency of hydrocarbon and heavy metal from road runoff.

CDS has been demonstrated to remove suspended solids and fractions of particles smaller than the screen aperture from stormwater [130]. This new technology expands upon the more traditional HDVS systems by removing heavier particles such as sediments and debris with centrifugal forces, allowing them to settle at the bottom. At the same time, CDS is a coarse screening method for gross pollutant traps based on a non-blocking screen with a swirl chamber. It has a unique design that allows it to function without blocking flow, separating the solids and buoyant materials [131]. CDS systems operate at a lower maintenance frequency than alternative technologies thanks to their self-cleaning capabilities, resulting in minimized operational costs. They are well-integrated with existing infrastructure and withstand flow variability, but offer greater flexibility to accommodate different environmental conditions. Copper, lead, chromium, and manganese have been efficiently removed using CDS, whereas it has shown less success with nickel, zinc, and nitrogen [132].

SPLITT fractionation is another type of treatment system using combined screening and settling processes, which has showed excellent ability in removing metallic pollutants <50 µm [133]. Provisional Green Infrastructure (PGI) has been constructed with the provision of silt traps and biofilters, and those have critically achieved an efficient removal rate for suspended solids and phosphorus, from 50 to 90%. However, they cannot substitute conventional wastewater treatment plants [134]. PGI is proven to be complementary in pollution control, which emphasizes the need for a combination of technologies for overall treatment. A Macro-pervious Pavement System (MPPS), containing a floating mat interceptor for oil and a settling tank for particles, achieved a high removal efficiency of hydrocarbons and heavy metals from road runoff, indicating the capability of MPPS to sustainably manage the runoff quality in highly vehicle-traffic-affected urban regions [135].

3.5. Advantages of CDS Technology

There are many benefits of CDS technology as compared to hydrodynamic separators. The most notable improvement is its higher pollutant removal efficiency. CDS systems have a removal rate exceeding 80% for both coarse and fine particles, and thus they can target the urban complexities of stormwater runoff effectively. In contrast to common size-based separators, which are often challenged by fine sediments, CDS technology's controlled vortex flow improves the pollution capture rate and has the best overall system performance [69].

From an operational angle, CDS systems are less challenging to introduce because of their smaller footprint, facilitating their use within an existing stormwater management framework. They can be easily installed in different environments, without the need to make major changes to the existing infrastructure. This feature is beneficial for municipalities because it enhances stormwater treatment capabilities without the need for substantial capital investments [71]. Moreover, a lower risk of clogging due to a simple CDS design translates into low maintenance and operational costs. Thus, owing to their high pollutant removal and low operational hindrances, CDS technologies offer a more sustainable and efficient approach, especially since they can be effective under high-variance flow conditions in which other technologies struggle [72].

Table 7 compares the basic features of conventional hydrodynamic separators, HDVS, and CDS systems. These synergies and efficiencies associated with CDS technology illustrate its operational advantages over the parallel screening and parsing approach of traditional stormwater weir systems, and its superior overall results are also shown by this analysis.

Table 7. Comparison of hydrodynamic separation technologies.

Attribute	HDS	HDVS	CDS
Pollutant removal efficiency	60–70% for coarse particles [90].	70–80% for fine particles [97].	Exceeding 80% for coarse and fine particles [136].
Mechanism of operation	Size and density-based separation [119].	Vortex flow with size-based separation [137].	Controlled vortex flow with deflection plates [138].
Performance under variable flow	Reduced efficiency at high flow rates [139].	Improved performance, but may still struggle [94].	Maintains high efficiency under variable flow conditions [140].
Space requirements	Larger footprint needed for effective operation [119].	Compact design, space-saving benefits [141].	Very compact, easily integrated into existing systems [142].
Maintenance requirements	Moderate; potential for clogging [143].	Lower than traditional separators [144].	Low; designed to minimize clogging and operational issues [145].
Initial investment cost	Typically lower initial costs [146].	Moderate investment needed for installation [147].	Potentially higher, but cost-effective over time due to efficiency and low maintenance [148].
Integration with existing systems	May require significant modifications [149].	Can be retrofitted into some systems [150].	Easily integrated with minimal disruption [151].
Environmental impact	May not effectively address all pollutants [152].	Good for fine sediment, but limited in some scenarios [153].	Comprehensive approach, effectively manages a wide range of pollutants [154].

The benefits of CDS technology make it the ideal selection for contemporary stormwater management. Combined, they make it a more sustainable and economical solution for urban stormwater management.

3.6. Future Trends and Research Gaps

Continued research into advanced stormwater and wastewater treatment is needed to process new classes of emerging contaminants that might adversely affect the environment, and to improve efficiency of existing systems. Below are some of the highlights for future work.

The performance of separation systems is greatly influenced by seasonal changes. For this reason, in small-scale systems driven by particle settling times, the efficiency significantly decreases during winter. LID filtration designs have the least variation in performance from summer to winter [155]. As a result, the use of soil bacteria to purify nutrients from road-salt-laden stormwater in cold climates is being introduced in several cities [60]. Moreover, the ability of treatment methods to perform can differ widely based on both geography and season, with clearly limited universal applicability. In addition, different land use types result in different pollutant characteristics and distributions, suggesting that the most suitable treatment devices will also be different [50] and should be selected to best fit the purpose. Balancing efficiency and cost will be crucial for optimizing future applications.

Many studies use models for simulating the pollutant removal efficiency in their design [156,157]. However, models may underestimate the measurements when predicting pollutant concentrations [158], limiting their applicability in real-life situations. Similar bias arises when using continuous simulation models (like the Storm Water Management Model (SWMM)) with historical rainfall data, which may not simulate the full complexity of all events [54]. Addressing these challenges will be an important focus in future research. The fusion of data-driven models, especially machine learning, with more traditional numerical models like computational fluid dynamics (CFD) can provide strong capabilities for tackling these challenges [159].

Since all processes of separation are effective for some pollutants, there is a chance to improve stormwater treatment by combining different technologies. Pairing CDS, MPPS, and PGI with CFS within combined separation systems is effective in the treatment of diverse pollutants such as suspended solids, metals, nitrogen, and oils. Nevertheless, its potential in removing organic pollutants and biological contaminants can be further enhanced [131,132,134,135]. Integrated systems may also offer a multi-barrier approach to pollutant removal by linking mechanical, biological, and chemical processes in a single system, which can enhance the overall treatment performance.

Another area that could be developed in further studies is advanced filter media to target specific pollutants. Filtration of a wider pool of contaminants can be performed efficiently with filters by utilizing their properties and modifications, based on the material quality of filter media. Because of its low cost and environmental friendliness, biochar is capable to be used as a filter medium [160–163]. New applications of biochar should be investigated for potential use as a water retention or even filtration system [164–166].

In addition, both newly emerging as well as persistently occurring contaminants such as microplastics and pharmaceuticals need further research [167,168]. Ultimately, innovative solutions and non-targeted detection methods to reduce the impacts of these pollutants in urban water systems are needed [169,170]. Studies over longer time frames are necessary to understand both the environmental impacts of current treatment solutions and the potential advantages that proposed innovations may provide. Research of this kind can help reduce the environmental impact of water treatment plants and guarantee urban sustainability.

By addressing these points, future work and investigation can fill the gaps present in the existing knowledge base, allowing for more efficient and sustainable water management solutions. Taking a whole-of-water-cycle approach will safeguard urban water quality and limit the environmental consequences of stormwater and wastewater.

4. Conclusions

Effective stormwater management is essential in mitigating the increasing and polluting stormwater runoff and urban flooding risks associated with growing urbanization. This paper has reviewed recent HDS technologies for managing urban stormwater, highlighting the advantages of combined separation processes over single-technology strategies in handling complex pollutants.

HDS had been discussed based on different treatment mechanisms. Filtration-based stormwater separation techniques are most widely used, followed by settling, flotation, and screening. Combined separation processes are found to be more efficient than single-technology strategies in handling complex pollutant profiles. Novel systems like CDS, SPLITT fractionation, PGI, and MPPS have successfully removed pollutants such as suspended solids, hydrocarbons, and heavy metals from urban runoff. CDS also overcomes the limitation on the maintenance and operation required in HDVS. Moving urban stormwater management systems toward hybrid styles that combine aspects of physical separation with NbS will be significant for developing countries seeking to meet SDGs and promote a circular economy.

Moreover, this paper has highlighted the vital gaps in our knowledge of stormwater treatment, which must be well-explored. Traditional separation systems struggle in cold climates due to seasonal changes. Biological treatment processes must include technologies that can withstand the temperature changes they will undergo. Previous models have followed the transport of materials in water, like metal contamination, but they can be imperfect. While these models could be improved, accuracy is needed when using machine learning with computer simulations. Current systems do well with solid waste but not so much for organic and biological contaminants. Accordingly, the development and search for combined mechanical, biological, and chemical treatment processes should be one of the main steps taken. Machine learning could also provide better monitoring and controls when integrating HDS systems.

Finally, the investigation of new filtration media like biochar may provide a low-cost and sustainable alternative. It is essential to examine the efficacy of these materials against a range of contaminants. The situation we face is being accelerated by a range of newly relevant pollutants, such as microplastics and pharmaceuticals, among other environmental pollutants, and it is a fresh challenge to detect and treat these pollutant families. While biochar is potentially necessary for Blue–Green Infrastructure (BGI), additional work is necessary on its ecological benefits, performance, and overall longevity. High-tech solutions for stormwater management need to be affordable, flexible, and recoverable. Understanding stormwater pollution is difficult, and research in these areas will be critical to its effective management.

Author Contributions: Conceptualization, Y.L.W. and F.Y.T.; methodology, Y.L.W., F.Y.T. and Y.C.; formal analysis, Y.L.W. and Y.C.; investigation, Y.L.W.; data curation, Y.L.W. and Y.C.; writing—original draft preparation, Y.L.W.; writing—review and editing, Y.C., A.S., C.L.L. and F.Y.T.; supervision, F.Y.T. and A.S.; project administration, Y.L.W. and F.Y.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data can be obtained upon request from the authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Aragon-Durand, F. Urbanisation and flood vulnerability in the peri-urban interface of Mexico City. *Disasters* **2007**, *31*, 477–494. [CrossRef] [PubMed]
2. Nirupama, N.; Simonovic, S.P. Increase of flood risk due to urbanisation: A canadian example. *Nat. Hazards* **2007**, *40*, 25–41. [CrossRef]
3. Korah, P.I.; Cobbinah, P.B. Juggling through Ghanaian urbanisation: Flood hazard mapping of Kumasi. *GeoJournal* **2017**, *82*, 1195–1212. [CrossRef]
4. Rossi, L.; De Alencastro, L.; Kupper, T.; Tarradellas, J. Urban stormwater contamination by polychlorinated biphenyls (PCBs) and its importance for urban water systems in Switzerland. *Sci. Total Environ.* **2004**, *322*, 179–189. [CrossRef]
5. Wong, T.; Brown, R. Water sensitive urban design. In *Water Resources Planning and Management*; Grafton, R.Q., Hussey, K., Eds.; Cambridge University Press: Cambridge, UK, 2011; pp. 483–504, ISBN 978-0-521-76258-8.
6. Feng, B.; Zhang, Y.; Bourke, R. Urbanization impacts on flood risks based on urban growth data and coupled flood models. *Nat. Hazards* **2021**, *106*, 613–627. [CrossRef]
7. Beshir, A.A.; Song, J. Urbanization and its impact on flood hazard: The case of Addis Ababa, Ethiopia. *Nat. Hazards* **2021**, *109*, 1167–1190. [CrossRef]
8. Carle, M.; Halpin, P.; Stow, C. Patterns of watershed urbanization and impacts on water quality. *J. Am. Water Resour. Assoc.* **2005**, *41*, 693–708. [CrossRef]
9. Di Salvo, C.; Ciotoli, G.; Pennica, F.; Cavinato, G.P. Pluvial flood hazard in the city of Rome (Italy). *J. Maps* **2017**, *13*, 545–553. [CrossRef]
10. Yang, L.; Ma, K.-M.; Zhao, J.-Z.; Bai, X.; Guo, Q.-H. The relationships of urbanization to surface water quality in four lakes of Hanyang, China. *Int. J. Sustain. Dev. World Ecol.* **2007**, *14*, 317–327. [CrossRef]
11. Yang, W.; Li, Y.; Liu, Y.; Xu, M.; Zhang, L.; Deng, Q. Impacts of rainfall intensity and urbanization on water environment of urban lakes. *Ecohydrol. Hydrobiol.* **2020**, *20*, 513–524. [CrossRef]
12. Gafri, H.; Zuki, F.; Zeeda, F.; Affan, N.; Sulaiman, A.; Norasiah, S. Study on Water Quality Status of Varsity Lake and Pantai River, Anak Air Batu River in Um Kuala Lumpur, Malaysia and Classify It Based ON (WQI) Malaysia. *EQA-Int. J. Environ. Qual.* **2018**, *29*, 51–65. [CrossRef]
13. San Liew, Y.; Desa, S.; Noh, M.; Tan, M.; Zakaria, N.; Chang, C. Assessing the Effectiveness of Mitigation Strategies for Flood Risk Reduction in the Segamat River Basin, Malaysia. *Sustainability* **2021**, *13*, 3286. [CrossRef]
14. Jarvie, J.; Arthur, S.; Beevers, L. *A Field Approach for Comparing the Ecosystem Services From Suds and Non-Suds Ponds: Preliminary Results*; Mynett, A., Ed.; IAHR: Beijing, China, 2015; pp. 382–391.
15. Melville-Shreeve, P.; Cotterill, S.; Grant, L.; Arahuetes, A.; Stovin, V.; Farmani, R.; Butler, D. State of SuDS delivery in the United Kingdom. *Water Environ. J.* **2018**, *32*, 9–16. [CrossRef]
16. El Hattab, M.; Mijic, A. Adaptation of SuDS Modelling Complexity to End-Use Application. In *New Trends in Urban Drainage Modelling*; Mannina, G., Ed.; Springer: Berlin/Heidelberg, Germany, 2019; pp. 91–95.
17. Humphrey, J.; Rowett, C.; Tyers, J.; Gregson, M.; Comber, S. Are sustainable drainage systems (SuDS) effective at retaining dissolved trace elements? *Environ. Technol.* **2023**, *44*, 1450–1463. [CrossRef]
18. Zhang, P.; Ariaratnam, S. Life cycle cost savings analysis on traditional drainage systems from low impact development strategies. *Front. Eng. Manag.* **2021**, *8*, 88–97. [CrossRef]
19. Jato-Espino, D.; Toro-Huertas, E.; Güereca, L. Lifecycle sustainability assessment for the comparison of traditional and sustainable drainage systems. *Sci. Total Environ.* **2022**, *817*, 152959. [CrossRef]
20. Duffy, A.; Jefferies, C.; Waddell, G.; Shanks, G.; Blackwood, D.; Watkins, A. A cost comparison of traditional drainage and SUDS in Scotland. *Water Sci. Technol.* **2008**, *57*, 1451–1459. [CrossRef]
21. Cojoc, L.; de Castro-Català, N.; de Guzmán, I.; González, J.; Arroita, M.; Besolí-Mestres, N.; Cadena, I.; Freixa, A.; Gutiérrez, O.; Larrañaga, A.; et al. Pollutants in urban runoff: Scientific evidence on toxicity and impacts on freshwater ecosystems. *Chemosphere* **2024**, *369*, 143806. [CrossRef]
22. Rathnayake, D.; Bal Krishna, K.C.; Kastl, G.; Sathasivan, A. The role of pH on sewer corrosion processes and control methods: A review. *Sci. Total Environ.* **2021**, *782*, 146616. [CrossRef]
23. Rodriguez, M.; Fu, G.; Butler, D.; Yuan, Z.; Cook, L. Global resilience analysis of combined sewer systems under continuous hydrologic simulation. *J. Environ. Manag.* **2023**, *344*, 118607. [CrossRef]

24. van der Werf, J.A.; Kapelan, Z.; Langeveld, J. Real-time control of combined sewer systems: Risks associated with uncertainties. *J. Hydrol.* **2023**, *617*, 128900. [CrossRef]
25. Brears, R.C. Blue-Green Infrastructure in Managing Urban Water Resources. In *Blue and Green Cities: The Role of Blue-Green Infrastructure in Managing Urban Water Resources*; Brears, R.C., Ed.; Palgrave Macmillan: London, UK, 2018; pp. 43–61, ISBN 978-1-137-59258-3.
26. Chung, M.G.; Frank, K.A.; Pokhrel, Y.; Dietz, T.; Liu, J. Natural infrastructure in sustaining global urban freshwater ecosystem services. *Nat. Sustain.* **2021**, *4*, 1068–1075. [CrossRef]
27. Osman, M.; Yusof, K.; Takaijudin, H.; Goh, H.; Malek, M.; Azizan, N.; Ab Ghani, A.; Abdurrasheed, A. A Review of Nitrogen Removal for Urban Stormwater Runoff in Bioretention System. *Sustainability* **2019**, *11*, 5415. [CrossRef]
28. Wong, T.H.F.; Eadie, M.L. Water sensitive urban design: A paradigm shift in urban design. In Proceedings of the 10th World Water Congress, Bali, Indonesia, 18–25 May 2000.
29. Sage, J.; Berthier, E.; Gromaire, M.-C. Stormwater Management Criteria for On-Site Pollution Control: A Comparative Assessment of International Practices. *Environ. Manag.* **2015**, *56*, 66–80. [CrossRef] [PubMed]
30. Liu, T.; Lawluvy, Y.; Shi, Y.; Yap, P. Low Impact Development (LID) Practices: A Review on Recent Developments, Challenges and Prospects. *Water. Air. Soil Pollut.* **2021**, *232*, 344. [CrossRef]
31. Wang, L.; Li, G.; Hu, X. Study on Sponge City Planning in Central City of Tangshan. In Proceedings of the 2017 International Conference on Materials, Energy, Civil Engineering and Computer (MATECC 2017), Sanya, China, 27–29 September 2017; Li, R., Ed.; pp. 59–65. [CrossRef]
32. Wang, Z.; Qi, F.; Liu, L.; Chen, M.; Sun, D.; Nan, J. How do urban rainfall-runoff pollution control technologies develop in China? A systematic review based on bibliometric analysis and literature summary. *Sci. Total Environ.* **2021**, *789*, 148045. [CrossRef]
33. Shafique, M.; Kim, R. Retrofitting the Low Impact Development Practices into Developed Urban areas Including Barriers and Potential Solution. *Open Geosci.* **2017**, *9*, 240–254. [CrossRef]
34. Gulshad, K.; Szydłowski, M.; Yaseen, A.; Aslam, R.W. A comparative analysis of methods and tools for low impact development (LID) site selection. *J. Environ. Manag.* **2024**, *354*, 120212. [CrossRef]
35. Hatt, B.E.; Morison, P.; Fletcher, T.D.; Deletic, A. *Stormwater Biofiltration Systems—Adoption Guidelines*; Monash University Publishing: Clayton, VIC, Australia, 2009; ISBN 978-0-9805831-1-3.
36. Pritchard, J.C.; Hawkins, K.M.; Cho, Y.-M.; Spahr, S.; Higgins, C.P.; Luthy, R.G. Flow rate and kinetics of trace organic contaminants removal in black carbon-amended engineered media filters for improved stormwater runoff treatment. *Water Res.* **2024**, *258*, 121811. [CrossRef]
37. Fitzgerald, J.; Laufer, J. Governing green stormwater infrastructure: The Philadelphia experience. *Local Environ.* **2017**, *22*, 256–268. [CrossRef]
38. Xia, J.; Zhang, Y.; Xiong, L.; He, S.; Wang, L.; Yu, Z. Opportunities and challenges of the Sponge City construction related to urban water issues in China. *Sci. China Earth Sci.* **2017**, *60*, 652–658. [CrossRef]
39. Pörtner, H.-O.; Roberts, D.; Tignor, M.; Poloczanska, E.; Mintenbeck, K.; Alegría, A.; Craig, M.; Langsdorf, S.; Löschke, S.; Möller, V.; et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability*; Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; IPCC: Geneva, Switzerland, 2022.
40. Vogel, J.R.; Moore, T.L. Urban Stormwater Characterization, Control, and Treatment. *Water Environ. Res.* **2016**, *88*, 1918–1950. [CrossRef] [PubMed]
41. Simpson, I.M.; Winston, R.J.; Brooker, M.R. Effects of land use, climate, and imperviousness on urban stormwater quality: A meta-analysis. *Sci. Total Environ.* **2022**, *809*, 152206. [CrossRef]
42. Rodak, C.; Moore, T.; David, R.; Jayakaran, A.; Vogel, J. Urban stormwater characterization, control, and treatment. *Water Environ. Res.* **2019**, *91*, 1034–1060. [CrossRef]
43. Qin, H.; He, K.; Fu, G. Modeling middle and final flush effects of urban runoff pollution in an urbanizing catchment. *J. Hydrol.* **2016**, *534*, 638–647. [CrossRef]
44. Xu, P.; He, J.; Zhang, Y.; Zhang, J.; Sun, K. Runoff Pollutant Characteristics and First Flush Analysis in Different Urban Functional Areas: A Case Study in China. *Fresenius Environ. Bull.* **2016**, *25*, 2444–2453.
45. Bach, P.M.; McCarthy, D.T.; Deletic, A. Redefining the stormwater first flush phenomenon. *Water Res.* **2010**, *44*, 2487–2498. [CrossRef]
46. Peter, K.T.; Hou, F.; Tian, Z.; Wu, C.; Goehring, M.; Liu, F.; Kolodziej, E.P. More Than a First Flush: Urban Creek Storm Hydrographs Demonstrate Broad Contaminant Pollutographs. *Environ. Sci. Technol.* **2020**, *54*, 6152–6165. [CrossRef]
47. Chen, Y.; Wang, Y.; Chia, B.; Wang, D. Upstream-downstream water quality comparisons of restored channelized streams. *Ecol. Eng.* **2021**, *170*, 106367. [CrossRef]
48. Yang, L.; Li, J.; Zhou, K.; Feng, P.; Dong, L. The effects of surface pollution on urban river water quality under rainfall events in Wuqing district, Tianjin, China. *J. Clean. Prod.* **2021**, *293*, 126136. [CrossRef]

49. He, T.; Xue, C.; Li, J.; Wang, W.; Du, X.; Gong, Y.; Zhao, Y.; Liang, M.; Ren, Y. Effects of Dry Periods on Nitrogen and Phosphorus Removal in Runoff Infiltration Devices and Their Biological Succession Patterns. *Water* **2024**, *16*, 2372. [CrossRef]
50. Jeon, J.C.; Kwon, K.H.; Jung, Y.J.; Kang, M.-J.; Min, K.S. Characteristics of stormwater runoff from junkyard. *Desalin. Water Treat.* **2015**, *53*, 3039–3047. [CrossRef]
51. Pieniaszek, A.; Wojciechowska, E.; Kulbat, E.; Nawrot, N.; Pempkowiak, J.; Obarska-Pempkowiak, H.; Czerwionka, K. Stormwater As An Alternative Water Source: Quality Changes With Rainfall Duration And Implications For Treatment Approaches. *Int. J. Conserv. Sci.* **2021**, *12*, 713–730.
52. Soonthornnonda, P.; Christensen, E.R. Source apportionment of pollutants and flows of combined sewer wastewater. *Water Res.* **2008**, *42*, 1989–1998. [CrossRef]
53. Deffontis, S.; Vialle, C.; Sablayrolles, C.; Breton, A.; Vignoles, C.; Montrejaud-Vignoles, M. Monitoring of stormwater between 2002 and 2010—What is the evolution of stormwater quality? *Fresenius Environ. Bull.* **2016**, *25*, 5650–5659.
54. Ying, G.; Sansalone, J. Granulometric relationships for urban source area runoff as a function of hydrologic event classification and sedimentation. *Water. Air. Soil Pollut.* **2008**, *193*, 229–246. [CrossRef]
55. Kim, J.; Sansalone, J. Event-based size distributions of particulate matter transported during urban rainfall-runoff events. *Water Res.* **2008**, *42*, 2756–2768. [CrossRef]
56. Zhou, Y.; Zhang, P.; Zhang, Y.; Li, J.; Zhang, T.; Yu, T. Total and settling velocity-fractionated pollution potential of sewer sediments in Jiaxing, China. *Environ. Sci. Pollut. Res.* **2017**, *24*, 23133–23143. [CrossRef]
57. Sakson, G.; Brzezinska, A.; Zawilski, M. Emission of heavy metals from an urban catchment into receiving water and possibility of its limitation on the example of Lodz city. *Environ. Monit. Assess.* **2018**, *190*, 281. [CrossRef]
58. Ozaki, N.; Yamauchi, T.; Kindaichi, T.; Ohashi, A. Stormwater inflow loading of polycyclic aromatic hydrocarbons into urban domestic wastewater treatment plant for separate sewer system. *Water Sci. Technol.* **2019**, *79*, 1426–1436. [CrossRef]
59. Järlskog, I.; Strömvall, A.-M.; Magnusson, K.; Galfi, H.; Björklund, K.; Polukarova, M.; Garção, R.; Markiewicz, A.; Aronsson, M.; Gustafsson, M.; et al. Traffic-related microplastic particles, metals, and organic pollutants in an urban area under reconstruction. *Sci. Total Environ.* **2021**, *774*, 145503. [CrossRef] [PubMed]
60. Endreny, T.; Burke, D.J.; Burchhardt, K.M.; Fabian, M.W.; Kretzer, A.M. Bioretention column study of bacteria community response to salt-enriched artificial stormwater. *J. Environ. Qual.* **2012**, *41*, 1951–1959. [CrossRef] [PubMed]
61. Hou, F.; Tian, Z.; Peter, K.T.; Wu, C.; Gipe, A.D.; Zhao, H.; Alegria, E.A.; Liu, F.; Kolodziej, E.P. Quantification of organic contaminants in urban stormwater by isotope dilution and liquid chromatography-tandem mass spectrometry. *Anal. Bioanal. Chem.* **2019**, *411*, 7791–7806. [CrossRef] [PubMed]
62. Morihama, A.C.D.; Amaro, C.; Tominaga, E.N.S.; Yazaki, L.F.O.L.; Pereira, M.C.S.; Porto, M.F.A.; Mukai, P.; Lucci, R.M. Integrated solutions for urban runoff pollution control in Brazilian metropolitan regions. *Water Sci. Technol.* **2012**, *66*, 704–711. [CrossRef]
63. Petrie, B. A review of combined sewer overflows as a source of wastewater-derived emerging contaminants in the environment and their management. *Environ. Sci. Pollut. Res.* **2021**, *28*, 32095–32110. [CrossRef]
64. Soupir, M.; Mostaghimi, S.; Love, N. Method to Partition Between Attached and Unattached E-coli in Runoff from Agricultural Lands. *J. Am. Water Resour. Assoc.* **2008**, *44*, 1591–1599. [CrossRef]
65. Fan, L.; Mohseni, A.; Schmidt, J.; Evans, B.; Murdoch, B.; Gao, L. Efficiency of lagoon-based municipal wastewater treatment in removing microplastics. *Sci. Total Environ.* **2023**, *876*, 162714. [CrossRef]
66. Iannuzzi, Z.; Mourier, B.; Winiarski, T.; Lipeme-Kouyi, G.; Polomé, P.; Bayard, R. Contribution of different land use catchments on the microplastic pollution in detention basin sediments. *Environ. Pollut.* **2024**, *348*, 123882. [CrossRef]
67. Ong, Z.C.; Asadsangabifard, M.; Ismail, Z.; Tam, J.H.; Roushenas, P. Design of a compact and effective greywater treatment system in Malaysia. *Desalin. Water Treat.* **2019**, *146*, 141–151. [CrossRef]
68. Mannina, G.; Viviani, G. Separate and combined sewer systems: A long-term modelling approach. *Water Sci. Technol.* **2009**, *60*, 555–565. [CrossRef]
69. Singh, K.; Bonthu, S.; Purvaja, R.; Robin, R.; Kannan, B.; Ramesh, R. Prediction of heavy rainfall over Chennai Metropolitan City, Tamil Nadu, India: Impact of microphysical parameterization schemes. *Atmos. Res.* **2018**, *202*, 219–234. [CrossRef]
70. Saleh, I.A.; Zouari, N.; Al-Ghouti, M.A. Removal of pesticides from water and wastewater: Chemical, physical and biological treatment approaches. *Environ. Technol. Innov.* **2020**, *19*, 101026. [CrossRef]
71. Saravanan, A.; Senthil Kumar, P.; Jeevanantham, S.; Karishma, S.; Tajsabreen, B.; Yaashikaa, P.R.; Reshma, B. Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development. *Chemosphere* **2021**, *280*, 130595. [CrossRef] [PubMed]
72. Shah, M.; Zahari, N.; Said, N.; Sidek, L.; Basri, H.; Noor, M.; Husni, M.; Jajarmizadeh, M.; Roseli, Z.; Dom, N. *Gross Pollutant Traps: Wet Load Assessment at Sungai Kerayong, Malaysia*; Shamsuddin, A., AbdRahman, A., Misran, H., Eds.; IOP: London, UK, 2016; Volume 32.
73. Sidek, L.; Basri, H.; Lee, L.; Foo, K. The performance of gross pollutant trap for water quality preservation: A real practical application at the Klang Valley, Malaysia. *Desalin. Water Treat.* **2016**, *57*, 24733–24741. [CrossRef]

74. Zahari, N.; Sidek, L.; Basri, H.; Said, N.; Noor, M.; Jajarmizadeh, M.; Abidin, M.; Dom, N. *Wet Load Study of Gross Pollutant Traps: Kemensah River, Malaysia*; Shamsuddin, A., AbdRahman, A., Misran, H., Eds.; IOP: London, UK, 2016; Volume 32.
75. Nayeb Yazdi, M.; Scott, D.; Sample, D.J.; Wang, X. Efficacy of a retention pond in treating stormwater nutrients and sediment. *J. Clean. Prod.* **2021**, *290*, 125787. [CrossRef]
76. Wilson, M.A.; Mohseni, O.; Gulliver, J.S.; Hozalski, R.M.; Stefan, H.G. Assessment of Hydrodynamic Separators for Storm-Water Treatment. *J. Hydraul. Eng.* **2009**, *135*, 383–392. [CrossRef]
77. Arya, S.; Kumar, A. Evaluation of stormwater management approaches and challenges in urban flood control. *Urban Clim.* **2023**, *51*, 101643. [CrossRef]
78. Quigley, M.M. The Integrated Unit Process Design Approach for Urban Water Quality Design. In *World Water and Environmental Resources Congress 2005, Impacts of Global Climate Change*; Walton, R., Ed.; American Society of Civil Engineers: Reston, VA, USA, 2005; p. 192.
79. Minton, G.R. A Tower of Babel: A Systems-Based Approach Toward an Integrative Management Strategy. *J. Surf. Water Qual. Prof. Stormwater* **2007**.
80. Shrestha, R.R.; Brodie, I.M. *Classification of Stormwater Treatment Devices for Performance Evaluation*; University of Southern Queensland: Brisbane, QLD, Australia, 2011.
81. Yagna Prasad, K. Sedimentation in Water and Used Water Purification. In *Handbook of Water and Used Water Purification*; Lahnsteiner, J., Ed.; Springer International Publishing: Cham, Switzerland, 2019; pp. 1–27, ISBN 978-3-319-66382-1.
82. Yokojima, S.; Takashima, R.; Asada, H.; Miyahara, T. Impacts of particle shape on sedimentation of particles. *Eur. J. Mech.-BFluids* **2021**, *89*, 323–331. [CrossRef]
83. Fassman, E. Stormwater BMP treatment performance variability for sediment and heavy metals. *Sep. Purif. Technol.* **2012**, *84*, 95–103. [CrossRef]
84. Yu, J.; Kim, Y.; Kim, Y. Removal of non-point pollutants from bridge runoff by a hydrocyclone using natural water head. *Front. Environ. Sci. Eng.* **2013**, *7*, 886–895. [CrossRef]
85. Rommel, S.H.; Gelhardt, L.; Welker, A.; Helmreich, B. Settling of road-deposited sediment: Influence of particle density, shape, low temperatures, and deicing salt. *Water Switz.* **2020**, *12*, 3126. [CrossRef]
86. Ferreira, M.; Stenstrom, M. The Importance of Particle Characterization in Stormwater Runoff. *Water Environ. Res.* **2013**, *85*, 833–842. [CrossRef] [PubMed]
87. Brooks, J.M.; Stewart, C.J.; Haberstroh, C.J.; Arias, M.E. Characteristics and fate of plastic pollution in urban stormwater ponds. *Environ. Pollut.* **2023**, *320*, 121052. [CrossRef] [PubMed]
88. Shammaa, Y.; Zhu, D.Z.; Gyũrék, L.L.; Labatiuk, C.W. Effectiveness of dry ponds for stormwater total suspended solids removal. *Can. J. Civ. Eng.* **2002**, *29*, 316–324. [CrossRef]
89. Yelton, R. Cleaning the: Marketing the separation units allows producers to expand their markets. *Concr. Prod.* **2009**, *27*, 41–42.
90. Tran, D.; Kang, J.-H. Optimal design of a hydrodynamic separator for treating runoff from roadways. *J. Environ. Manag.* **2013**, *116*, 1–9. [CrossRef]
91. Lee, D.H.; Min, K.S.; Kang, J.-H. Performance evaluation and a sizing method for hydrodynamic separators treating urban stormwater runoff. *Water Sci. Technol.* **2014**, *69*, 2122–2131. [CrossRef]
92. Brown, J.; Stein, E.; Ackerman, D.; Dorsey, J.; Lyon, J.; Carter, P. Metals and bacteria partitioning to various size particles in Ballona creek storm water runoff. *Environ. Toxicol. Chem.* **2013**, *32*, 320–328. [CrossRef]
93. Meroney, R.N.; Sheker, R.E. Removing grit during wastewater treatment: CFD Analysis of HDVS performance. *Water Environ. Res.* **2016**, *88*, 438–448. [CrossRef]
94. Mahaveer, M.; You, X.-Y. Optimization of hydrodynamic vortex separator for removal of sand particles from storm water by computational fluid dynamics. *Desalin. Water Treat.* **2021**, *223*, 54–70. [CrossRef]
95. Heist, J.; Davey, A.; Hawkins, R.; Fitzgerald, J.; Warren, P. Continuous Deflective Separation (CDS) Use for Treating Sanitary Wet Weather Flows. In Proceedings of the World Water and Environmental Resources Congress 2004, Salt Lake City, UT, USA, 27 July 2004; p. 10, ISBN 978-0-7844-0737-0.
96. Petavy, F.; Ruban, V.; Conil, P.; Viau, J.Y. Reduction of sediment micro-pollution by means of a pilot plant. *Water Sci. Technol.* **2008**, *57*, 1611–1617. [CrossRef] [PubMed]
97. Kwon, K.-H.; Kim, S.-W.; Kim, L.-H.; Kim, J.H.; Lee, S.; Min, K.-S. Particle removal properties of stormwater runoff with a lab-scale vortex separator. *Desalin. Water Treat.* **2012**, *38*, 349–353. [CrossRef]
98. Neupert, J.W.; Lau, P.; Venghaus, D.; Barjenbruch, M. Development of a new testing approach for decentralised technical sustainable drainage systems. *Water Switz.* **2021**, *13*, 722. [CrossRef]
99. Ismail, M.; Nikraz, H. Rocla Versatraps: Laboratory performance trials. *Water* **2007**, *34*, 67–72.
100. Liu, L.; Sun, Y.; Kleinmeyer, Z.; Habil, G.; Yang, Q.; Zhao, L.; Rosso, D. Microplastics separation using stainless steel mini-hydrocyclones fabricated with additive manufacturing. *Sci. Total Environ.* **2022**, *840*, 156697. [CrossRef]

101. Chen, S.; Qin, H.-P.; Zheng, Y.; Fu, G. Spatial variations of pollutants from sewer interception system overflow. *J. Environ. Manag.* **2019**, *233*, 748–756. [CrossRef]
102. Radzuan, M.; Belope, M.; Thorpe, R. Removal of fine oil droplets from oil-in-water mixtures by dissolved air flotation. *Chem. Eng. Res. Des.* **2016**, *115*, 19–33. [CrossRef]
103. Piaggio, A.L.; Soares, L.A.; Balakrishnan, M.; Guleria, T.; de Kreuk, M.K.; Lindeboom, R.E.F. High suspended solids removal of Indian drain water with a down-scaled Dissolved Air Flotation (DAF) for water recovery. Assessing water-type dependence on process control variables. *Environ. Chall.* **2022**, *8*, 100567. [CrossRef]
104. Rajapakse, N.; Zargar, M.; Sen, T.; Khiadani, M. Effects of influent physicochemical characteristics on air dissolution, bubble size and rise velocity in dissolved air flotation: A review. *Sep. Purif. Technol.* **2022**, *289*, 120772. [CrossRef]
105. Velautham, K.D.; Chelliapan, S.; Kamaruddin, S.A.; Meyers, J.L. Design requirements for the treatment of stormwater contaminated with jet fuel oil using corrugated plate interceptor. *Egypt. J. Chem.* **2022**, *65*, 1–10.
106. Tarnowski, K.; Bering, S.; Głowacka, A.; Mazur, J. Oil derivatives separating efficiency in treatment of water contaminated with diesel oil with bio-components. *Desalin. Water Treat.* **2018**, *134*, 52–56. [CrossRef]
107. Tang, Y.; Zhu, D.Z.; van Duin, B. Note on sediment removal efficiency in oil-grit separators. *Water Sci. Technol.* **2018**, *2017*, 729–735. [CrossRef]
108. Peters, C.; Keller, S.; Sieker, H.; Jekel, M. Potentials of real time control, stormwater infiltration and urine separation to minimize river impacts: Dynamic long term simulation of sewer network, pumping stations, pressure pipes and waste water treatment plant. *Water Sci. Technol.* **2007**, *56*, 1–10. [CrossRef]
109. Gevaert, V.; Verdonck, F.; De Baets, B. A scenario analysis for reducing organic priority pollutants in receiving water using integrated dynamic urban fate models. *Sci. Total Environ.* **2012**, *432*, 422–431. [CrossRef]
110. Liu, S.; Wu, J.; Sun, L.; Huang, M.; Qiu, X.; Tang, H.; Liu, J.; Wu, P. Analysis and study of the migration pattern of microplastic particles in saturated porous media pavement. *Sci. Total Environ.* **2023**, *861*, 160613. [CrossRef]
111. Ranieri, V.; Coropulis, S.; Fedele, V.; Intini, P.; Sansalone, J. Flexible Permeable-Pavement System Sustainability: A Methodology for Stormwater Management Based on PM Granulometry. *Infrastructures* **2024**, *9*, 95. [CrossRef]
112. Kinzelman, J.; Byappanahalli, M.N.; Nevers, M.B.; Shively, D.; Kurdas, S.; Nakatsu, C. Utilization of multiple microbial tools to evaluate efficacy of restoration strategies to improve recreational water quality at a Lake Michigan Beach (Racine, WI). *J. Microbiol. Methods* **2020**, *178*, 106049. [CrossRef]
113. Niu, S.; Song, X.; Yu, J.; Kim, Y. Nitrogen reduction by fill-and-drain wetland receiving high pollution stormwater from impervious road generated by the initial precipitation. *Desalin. Water Treat.* **2020**, *203*, 150–159. [CrossRef]
114. Jiang, C.; Li, J.; Li, H.; Li, Y. Nitrogen retention and purification efficiency from rainfall runoff via retrofitted bioretention cells. *Sep. Purif. Technol.* **2019**, *220*, 25–32. [CrossRef]
115. Endreny, T.; Collins, V. Implications of bioretention basin spatial arrangements on stormwater recharge and groundwater mounding. *Ecol. Eng.* **2009**, *35*, 670–677. [CrossRef]
116. Christoffels, E.; Brunsch, A.; Wunderlich-Pfeiffer, J.; Mertens, F.M. Monitoring micropollutants in the Swist river basin. *Water Sci. Technol.* **2016**, *74*, 2280–2296. [CrossRef] [PubMed]
117. Mohammed, T.; Vigneswaran, S.; Loganathan, P.; Kandasamy, J.; Aryal, R. Removal of Inorganic Contaminants from Simulated Stormwater by Three Sorbents in Columns Under Intermittent Runoff Condition. *Sep. Sci. Technol.* **2012**, *47*, 2340–2347.
118. Ahmadi, A.; Yang, W.; Jones, S.; Wu, T. Separation-free Al-Mg/graphene oxide composites for enhancement of urban stormwater runoff quality. *Adv. Compos. Hybrid Mater.* **2018**, *1*, 591–601. [CrossRef]
119. Liu, D.; Sansalone, J.J.; Cartledge, F.K. Comparison of sorptive filter media for treatment of metals in runoff. *J. Environ. Eng.* **2005**, *131*, 1178–1186. [CrossRef]
120. Huber, M.; Hilbig, H.; Badenberg, S.C.; Fassnacht, J.; Drewes, J.E.; Helmreich, B. Heavy metal removal mechanisms of sorptive filter materials for road runoff treatment and remobilization under de-icing salt applications. *Water Res.* **2016**, *102*, 453–463. [CrossRef]
121. Murray, A.; Örmeci, B. Removal effectiveness of nanoplastics (<400 nm) with separation processes used for water and wastewater treatment. *Water Switz.* **2020**, *12*, 635. [CrossRef]
122. Zhou, J.; Xiong, J.; Hu, T.; Xia, Q. Loess-loaded silica gel materials for stormwater management facilities: Hydrology and water quality. *Sep. Purif. Technol.* **2024**, *352*, 127949. [CrossRef]
123. Ataguba, C.O.; Brink, I. A comparison of oil and grease removal from automobile workshop stormwater runoff using gravel, granular activated carbon, rice husk and conventional oil and grease (O&G) trap. *Water SA* **2022**, *48*, 50–55. [CrossRef]
124. Samuel, M.P.; Senthilvel, S.; Tamilmani, D.; Mathew, A.C. Performance evaluation and modelling studies of gravel-coir fibre-sand multimedia stormwater filter. *Environ. Technol.* **2012**, *33*, 2057–2069. [CrossRef]
125. Al-Mashaqbeh, O.; McLaughlan, R. Non-equilibrium zinc uptake onto compost particles from synthetic stormwater. *Bioresour. Technol.* **2012**, *123*, 242–248. [CrossRef] [PubMed]

126. Kayhanian, M.; Givens, B. Processing and analysis of roadway runoff micro (<20 μm) particles. *J. Environ. Monit.* **2011**, *13*, 2720–2727. [CrossRef] [PubMed]
127. Raspati, G.S.; Haug Lindseth, H.K.; Muthanna, T.M.; Azrague, K. Potential of biofilters for treatment of de-icing chemicals. *Water Switz.* **2018**, *10*, 620. [CrossRef]
128. Scholz, M.; Xu, J.; Dodson, H.I. Comparison of Filter Media, Plant Communities and Microbiology within Constructed Wetlands Treating Wastewater Containing Heavy Metals. *J. Chem. Technol. Biotechnol.* **2001**, *76*, 827–835. [CrossRef]
129. Zakharova, J.; Pouran, H.; Wheatley, A.; Arif, M. Assessment of oil-interceptor performance for solid removal in highway runoff. *Environ. Technol.* **2023**, *44*, 197–210. [CrossRef]
130. Jago, R.A. Advances in stormwater pollution control. *Water* **2000**, 49–50.
131. Jago, R.A.; Davey, A. The CDS story: Continuous innovation. *Water* **2002**, *29*, 64–68.
132. Birch, H.; Gouliarmou, V.; Lützhoft, H.-C.H.; Mikkelsen, P.S.; Mayer, P. Passive dosing to determine the speciation of hydrophobic organic chemicals in aqueous samples. *Anal. Chem.* **2010**, *82*, 1142–1146. [CrossRef]
133. Magnuson, M.; Kelty, C.; Kelty, K. Trace metal loading on water-borne soil and dust particles characterized through the use of split-flow thin cell fractionation. *Anal. Chem.* **2001**, *73*, 3492–3496. [CrossRef]
134. Phillips, D.; Jamwal, P.; Lindquist, M.; Gronewold, A. Assessing catchment-scale performance of in-stream Provisional Green Infrastructure interventions for Dry Weather Flows. *Landsc. Urban Plan.* **2022**, *226*, 104448. [CrossRef]
135. Newman, A.P.; Aitken, D.; Antizar-Ladislao, B. Stormwater quality performance of a macro-pervious pavementcar park installation equipped with channel drainbased oil and silt retention devices. *Water Res.* **2013**, *47*, 7327–7336. [CrossRef] [PubMed]
136. Yang, L.H.; Chen, C.Y.; Hsu, W.Y.; Fukui, K.; Fukasawa, T.; Huang, A.N.; Kuo, H.P. Effect of the operation temperature on the hydrodynamics and performances of a cyclone separator. *Adv. Powder Technol.* **2022**, *33*, 103791. [CrossRef]
137. Hreiz, R.; Gentric, C.; Midoux, N.; Lainé, R.; Fünfschilling, D. Hydrodynamics and velocity measurements in gas–liquid swirling flows in cylindrical cyclones. *Chem. Eng. Res. Des.* **2014**, *92*, 2231–2246. [CrossRef]
138. Zhou, Y.; Xu, Z.; Xiao, G.; Hu, X.; Chen, H.; Zhang, R.; Luo, X.; Wang, J.; Yang, Y. Monitoring the hydrodynamics and critical variation of separation efficiency of cyclone separator via acoustic emission technique with multiple analysis methods. *Powder Technol.* **2020**, *373*, 174–183. [CrossRef]
139. Natarajan, P.; Davis, A.P. Ecological assessment of a transitioned stormwater infiltration basin. *Ecol. Eng.* **2016**, *90*, 261–267. [CrossRef]
140. Amiri, M.; Mikielewicz, J.; Mikielewicz, D. CO_2 capture using steam ejector condenser under electro hydrodynamic actuator with non-condensable gas and cyclone separator: A numerical study. *Sep. Purif. Technol.* **2024**, *329*, 125236. [CrossRef]
141. Chen, X.; Yu, C.; Wang, L.; Yu, B. A comprehensive review of the bio-corrosion mechanisms, hydrodynamics and antifouling measures on marine concrete. *Ocean Eng.* **2024**, *310*, 118696. [CrossRef]
142. Jurczak, T.; Wagner, I.; Kaczkowski, Z.; Szklarek, S.; Zalewski, M. Hybrid system for the purification of street stormwater runoff supplying urban recreation reservoirs. *Ecol. Eng.* **2018**, *110*, 67–77. [CrossRef]
143. Kourtis, I.M.; Tsihrintzis, V.A. Adaptation of urban drainage networks to climate change: A review. *Sci. Total Environ.* **2021**, *771*, 145431. [CrossRef]
144. Fowdar, H.S.; Neo, T.H.; Ong, S.L.; Hu, J.; McCarthy, D.T. Performance analysis of a stormwater green infrastructure model for flow and water quality predictions. *J. Environ. Manag.* **2022**, *316*, 115259. [CrossRef]
145. Liu, H.; Sansalone, J. CFD and physical models of PM separation for urban drainage hydrodynamic unit operations. *Water Res.* **2019**, *154*, 258–266. [CrossRef] [PubMed]
146. Zhang, J.; Liu, H.; Yao, J.; Cao, S.; Liu, X.; Cheng, G.; Hu, Q.; Wang, F.; Zhang, Z. Hydrodynamic characteristics analysis of series hydraulic cyclone separators for pond aquaculture wastewater purification. *Aquac. Eng.* **2024**, *106*, 102436. [CrossRef]
147. Xi, J.; Zhou, Z.; Yuan, Y.; Xiao, K.; Qin, Y.; Wang, K.; An, Y.; Ye, J.; Wu, Z. Enhanced nutrient removal from stormwater runoff by a compact on-site treatment system. *Chemosphere* **2022**, *290*, 133314. [CrossRef]
148. Azad, A.; Sheikh, M.N.; Hai, F.I. A critical review of the mechanisms, factors, and performance of pervious concrete to remove contaminants from stormwater runoff. *Water Res.* **2024**, *251*, 121101. [CrossRef]
149. Saraswat, C.; Kumar, P.; Mishra, B.K. Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo. *Environ. Sci. Policy* **2016**, *64*, 101–117. [CrossRef]
150. Rohith, A.N.; Sudheer, K.P. A novel safe-fail framework for the design of urban stormwater drainage infrastructures with minimal failure and flood severity. *J. Hydrol.* **2023**, *627*, 130393. [CrossRef]
151. Xu, W.D.; Burns, M.J.; Cherqui, F.; Duchesne, S.; Pelletier, G.; Fletcher, T.D. Real-time controlled rainwater harvesting systems can improve the performance of stormwater networks. *J. Hydrol.* **2022**, *614*, 128503. [CrossRef]
152. Price, W.D.; Burchell, M.R.; Hunt, W.F.; Chescheir, G.M. Long-term study of dune infiltration systems to treat coastal stormwater runoff for fecal bacteria. *Ecol. Eng.* **2013**, *52*, 1–11. [CrossRef]

153. Monaghan, J.; Jaeger, A.; Agua, A.; Stanton, R.; Pirrung, M.; Gill, C.; Krogh, E. A Direct Mass Spectrometry Method for the Rapid Analysis of Ubiquitous Tire-Derived Toxin N-(1,3-Dimethylbutyl)-N′-phenyl-p-phenylenediamine Quinone (6-PPDQ). *Environ. Sci. Technol. Lett.* **2021**, *8*, 1051–1056. [CrossRef]
154. Li, H.; Shatarah, M. Operator learning for urban water clarification hydrodynamics and particulate matter transport with physics-informed neural networks. *Water Res.* **2024**, *251*, 121123. [CrossRef]
155. Roseen, R.M.; Ballestero, T.P.; Houle, J.J.; Avellaneda, P.; Briggs, J.; Fowler, G.; Wildey, R. Seasonal performance variations for storm-water management systems in cold climate conditions. *J. Environ. Eng.* **2009**, *135*, 128–137. [CrossRef]
156. Lee, J.H.; Bang, K.W.; Choi, C.S.; Lim, H.S. CFD modelling of flow field and particle tracking in a hydrodynamic stormwater separator. *Water Sci. Technol.* **2010**, *62*, 2381–2388. [CrossRef] [PubMed]
157. Ferrans, P.; Torres, M.N.; Temprano, J.; Rodríguez Sánchez, J.P. Sustainable Urban Drainage System (SUDS) modeling supporting decision-making: A systematic quantitative review. *Sci. Total Environ.* **2022**, *806*, 150447. [CrossRef] [PubMed]
158. Lindfors, S.; Österlund, H.; Lundy, L.; Viklander, M. Evaluation of measured dissolved and bio-met predicted bioavailable Cu, Ni and Zn concentrations in runoff from three urban catchments. *J. Environ. Manag.* **2021**, *287*, 112263. [CrossRef]
159. Li, B.; Yuan, D.; Gao, C.; Zhang, H.; Li, Z. Synthesis and characterization of TiO_2/ZnO heterostructural composite for ultraviolet photocatalytic degrading DOM in landfill leachate. *Environ. Sci. Pollut. Res.* **2022**, *29*, 85510–85524. [CrossRef]
160. Duwiejuah, A.B.; Abubakari, A.H.; Quainoo, A.K.; Amadu, Y. Review of Biochar Properties and Remediation of Metal Pollution of Water and Soil. *J. Health Pollut.* **2020**, *10*, 200902. [CrossRef]
161. Castiglioni, M.; Rivoira, L.; Ingrando, I.; Del Bubba, M.; Bruzzoniti, M.C. Characterization Techniques as Supporting Tools for the Interpretation of Biochar Adsorption Efficiency in Water Treatment: A Critical Review. *Molecules* **2021**, *26*, 5063. [CrossRef]
162. Chen, Y.; Wu, Q.; Tang, Y.; Liu, Z.; Ye, L.; Chen, R.; Yuan, S. Application of biochar as an innovative soil ameliorant in bioretention system for stormwater treatment: A review of performance and its influencing factors. *Water Sci. Technol.* **2022**, *86*, 1232–1252. [CrossRef]
163. Xiong, J.; Liang, L.; Shi, W.; Li, Z.; Zhang, Z.; Li, X.; Liu, Y. Application of biochar in modification of fillers in bioretention cells: A review. *Ecol. Eng.* **2022**, *181*, 106689. [CrossRef]
164. Mohanty, S.K.; Valenca, R.; Berger, A.W.; Yu, I.K.M.; Xiong, X.; Saunders, T.M.; Tsang, D.C.W. Plenty of room for carbon on the ground: Potential applications of biochar for stormwater treatment. *Sci. Total Environ.* **2018**, *625*, 1644–1658. [CrossRef]
165. Malyan, S.K.; Kumar, S.S.; Fagodiya, R.K.; Ghosh, P.; Kumar, A.; Singh, R.; Singh, L. Biochar for environmental sustainability in the energy-water-agroecosystem nexus. *Renew. Sustain. Energy Rev.* **2021**, *149*, 111379. [CrossRef]
166. Blanco-Alegre, C.; Pont, V.; Calvo, A.I.; Castro, A.; Oduber, F.; Pimienta-del-Valle, D.; Fraile, R. Links between aerosol radiative forcing and rain characteristics: Stratiform and convective precipitation. *Sci. Total Environ.* **2022**, *819*, 152970. [CrossRef] [PubMed]
167. Eramo, A.; Reyes, H.D.; Fahrenfeld, N.L. Partitioning of antibiotic resistance genes and fecal indicators varies intra and inter-storm during combined sewer overflows. *Front. Microbiol.* **2017**, *8*, 2024. [CrossRef] [PubMed]
168. Boni, W.; Arbuckle-Keil, G.; Fahrenfeld, N.L. Inter-storm variation in microplastic concentration and polymer type at stormwater outfalls and a bioretention basin. *Sci. Total Environ.* **2022**, *809*, 151104. [CrossRef]
169. Torres, A.; Bertrand-Krajewski, J.-L. Partial least squares local calibration of a UV-visible spectrometer used for in situ measurements of COD anD TSS concentrations in urban drainage systems. *Water Sci. Technol.* **2008**, *57*, 581–588. [CrossRef]
170. Aryal, R.; Chong, M.N.; Beecham, S.; Mainali, B. Identifying the first flush in stormwater runoff using UV spectroscopy. *Desalin. Water Treat.* **2017**, *96*, 231–236. [CrossRef]