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Review

Urban Stormwater Management Using Nature-Based Solutions: A Review and Conceptual Model of Floodable Parks

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Abstract: Climate change is causing the alteration of atmospheric dynamics, leading to extreme precipitation events and floods. On the other hand, landscape modification and increased imperviousness due to urbanization exacerbate the impacts of flooding. In order to become more permeable, cities are increasingly embracing aquatic Nature-based Solutions which, using natural processes, allow for the mitigation of water-related hazards. One of these solutions is floodable parks, where pluvial runoff is conveyed for its temporal storage into, firstly, permanent retention ponds and, eventually, the partial or totality of their surface. Floodable parks are still a novel aquatic Nature-based Solution and have not yet been investigated. In this paper, a systematic review on current floodable parks was performed in order to study (1) the conditions needed for their implementation, (2) their design, and (3) the connection between design and ecosystem services. A subsequent systematic review was performed to understand (4) the processes occurring within the park. With the obtained information, a conceptual model of floodable parks was developed. The results indicate that both the vegetation surrounding the permanent pond of the floodable park and the biodiversity within the pond enhance the performance of this solution and allow potential water reuse. The implementation of floodable parks will therefore facilitate the transformation of urban areas to create sustainable, climate-resilient, and circular cities.

Keywords: climate change; flooding; urban stormwater management; nature-based solutions; ecosystem services; floodable parks; biodiversity; water reuse; circularity; conceptual model

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1. Introduction

Rapid urbanization is a common phenomenon to both developed and developing countries, leading to uncontrolled urban sprawl and unsustainable land-use changes. Due to anthropogenic impacts such as deforestation, river plain modification, and increased imperviousness, flooding has intensified in the past decades [1]. Floods are currently the most common natural disaster in cities globally [2]. They caused a loss of approximately USD 826 billion in the period between 1960 and 2019 [3]; only the European floods in July 2021 costed USD 46 billion. The frequency of flooding has risen by 48% compared to historic levels [4], with climate change being the main driver of this increase [5]. Extreme droughts are also associated with the alteration of atmospheric dynamics, which have raised the urban water demand and caused severe water use restrictions in the most vulnerable regions [6].

Nature-based Solutions (NbSs) can be used as a tool to create greener and more sustainable cities and help tackle the aforementioned challenges [7]. NbSs are measures which use natural processes to provide environmental, social, and economic benefits and to increase resilience to climate-change hazards. NbSs have been promoted across Europe, the USA, and Australia through guidelines and policies which encourage water-sensitive urban design (WSUD), low-impact development (LID) practices, and best management practices

(BMPs), all being concepts that can be used interchangeably [8]. Aquatic NbSs (aNbSs) address, among others, water-related problems such as droughts and floods. Popular aNbSs are green roofs, bioswales, and artificial constructed or floating wetlands, as well as detention and retention ponds. Remarkably, all of these aNbSs can be integrated into the urban matrix in public spaces. In this paper, wet retention ponds will be studied within the concept of a floodable urban park for pluvial flood management.

Floodable urban parks with retention consist mainly of a permanent pond area with landscaped banks and surroundings which allow the storage of local runoff water [9]. Unlike normal parks with ponds or wadis, this aNbS is designed for its complete inundation (both banks and surroundings) in order to attenuate surface runoff during extreme precipitation events. Floodable parks with retention ponds (henceforth called floodable parks) can also provide a rich and stable ecosystem for biodiversity due to their permanent waterbody [10]. An additional benefit of this type of solution is that it can potentially be connected with treatment plants for the post-rainfall treatment of the stored water, such as in the “La Marjal” floodable park (Alicante, Spain), a model example of a circular water system [11]. Therefore, floodable parks are meant not only to tolerate runoff water, but also to store, harvest, and convey it, potentially working together with existing infrastructure as multifunctional modules [2].

Although floodable urban parks can incorporate in their design multiple aNBSs (e.g., rain gardens, vertical gardens), the main element which provides runoff attenuation is the permanent pond. Taking as reference previous works on floodable parks for coastal and fluvial flooding [12–15], we define floodable urban parks as recreational spaces to which pluvial water is conveyed into a stagnant waterbody for its retention, infiltration, and drainage and which can be temporarily flooded. However, not only water flow-regulating services are delivered by floodable urban parks, but also other co-benefits, such as water quality regulation, cultural and educational services, aesthetic value, biodiversity conservation, and even potable water. Despite the multiple ecosystem services (ESs) which are created by this aNbS, it has not been systematically studied under an ES perspective, nor have these ESs been correlated to the design.

This review seeks to address the following research questions: (i) what are the topographical and climatic conditions needed for the implementation of floodable parks, (ii) what are the key attributes required in the design of floodable parks, (iii) how are these attributes connected to the ESs and benefits that these parks deliver, and (iv) what are the occurring processes within the permanent pond which contribute to ES delivery. The aim of this article is thus to establish a holistic understanding of urban floodable parks and propose a graphical definition that can be used in further studies. In order to do so, a conceptual model was developed based on existing study cases. A conceptual model helps to promote an integrative approach when planning floodable parks as a sustainable solution for water regulation in cities.

2. Materials and Methods

2.1. Case Study Selection of Floodable Parks

An initial literature search was conducted using the Scopus and Web of Science online databases to find case studies from which to derive a conceptual model of a floodable park. Different combinations of search strings were used to search within the title, abstract, and keywords fields, tackling (1) infrastructure/solution, (2) location, (3) function/benefits, and (4) period of publication. The criteria of selection were: (i) it must be available in English or Spanish, (ii) the case study should be placed in urban or peri-urban areas, and (iii) it should have been constructed to prevent pluvial (not fluvial) flooding only. The initial search was (1) “floodable parks” OR “floodable urban landscape” OR “sustainable urban drainage systems” OR “water nature-based solution” OR “aqua nature-based solution” OR “aqua NBS”, (2) urban OR city, (3) “water management” OR “water reuse” OR “flood resilience” OR runoff, and (4) Jan 2014–Dec 2023. After this first search, 241 papers were found in Scopus and 152 in Web of Science. Since the search was too broad, a second search string was used: (1) "floodable parks" OR "floodable urban landscape" OR "sustainable urban drainage systems" OR "water nature-based solution" OR "aqua nature-based solution" OR "aqua NBS", (2) urban OR city, (3) "ecosystem services" OR "ecological benefits" OR "ecosystem benefits" OR "benefits", (4) January 2014–December 2023. In this case, 88 papers were found in Scopus and 58 in Web of Science. After title and abstract screening, it was observed that there were few examples in literature and therefore, that this solution has not yet been scientifically studied nor monitored. Therefore, the search was broadened to water engineering projects and municipality and architectural firm websites as well as newspapers. The following keywords were used, both in English and Spanish: "floodable parks", "sustainable urban drainage system", "flood-resilient urban park". Since the focus of this paper is on pluvial flood management, projects in which floodable parks were used to manage fluvial floods were excluded. Therefore, the case studies were selected for the presence of artificial ponds or pools within the urban park and importantly, for their ability to be temporarily inundated. Snowball techniques (e.g., taking referenced floodable parks from initially sampled respondents) were also used to look for the case studies. The search process is summarized in Figure 1. In total, 12 case studies were selected (Table 1).

Table 1. Summary of the selected case studies. The name of the park, year of construction, country, region, reference source, and its year of publication are presented.

Name	Year of Construction	Country	Region	Reference Source	Year of Publication
El Recorral Forest Park	2019	Spain	Alicante	Sánchez-Almodóvar et al. [16]	2022
Los Alcázares	Ongoing implementation	Spain	Murcia	Tragsatec Presupuestary document	2023
Via Parque	2023	Spain	Alicante	Sánchez-Almodóvar et al. [17]	2021
La Marjal	2015	Spain	Alicante	Sánchez-Almodóvar et al. [17]	2022
La Quebradora	Ongoing implementation	Mexico	Ciudad de Mexico	Perroti [18]	2022
Hans Tavsens Park	Not implemented yet	Denmark	Copenhagen	Soul of Norrebro booklet [19]	2019
Celso Peçanha	Not implemented yet	Brazil	Mesquita	Pitzer J. et al. [19,20]	2019
Maple Valley Park	2013	Taiwan	Taichung	Hsu C. & Hung C. [21]	2019
Enghaven Park	2019	Denmark	Copehnaghen	Braae, E., & Riesto, S. [22]	2018
Elsa Eschelsson's Park	2022	Sweden	Uppsala	http://lanzine.com/ (accessed on 10 April 2024) [23]	2022
Benthemplein	2013	Netherlands	Rotterdam	Peinhardt [24]	2021
Sidwell Friends School	2007	USA	Washington, D.C	Quach [25]	2021

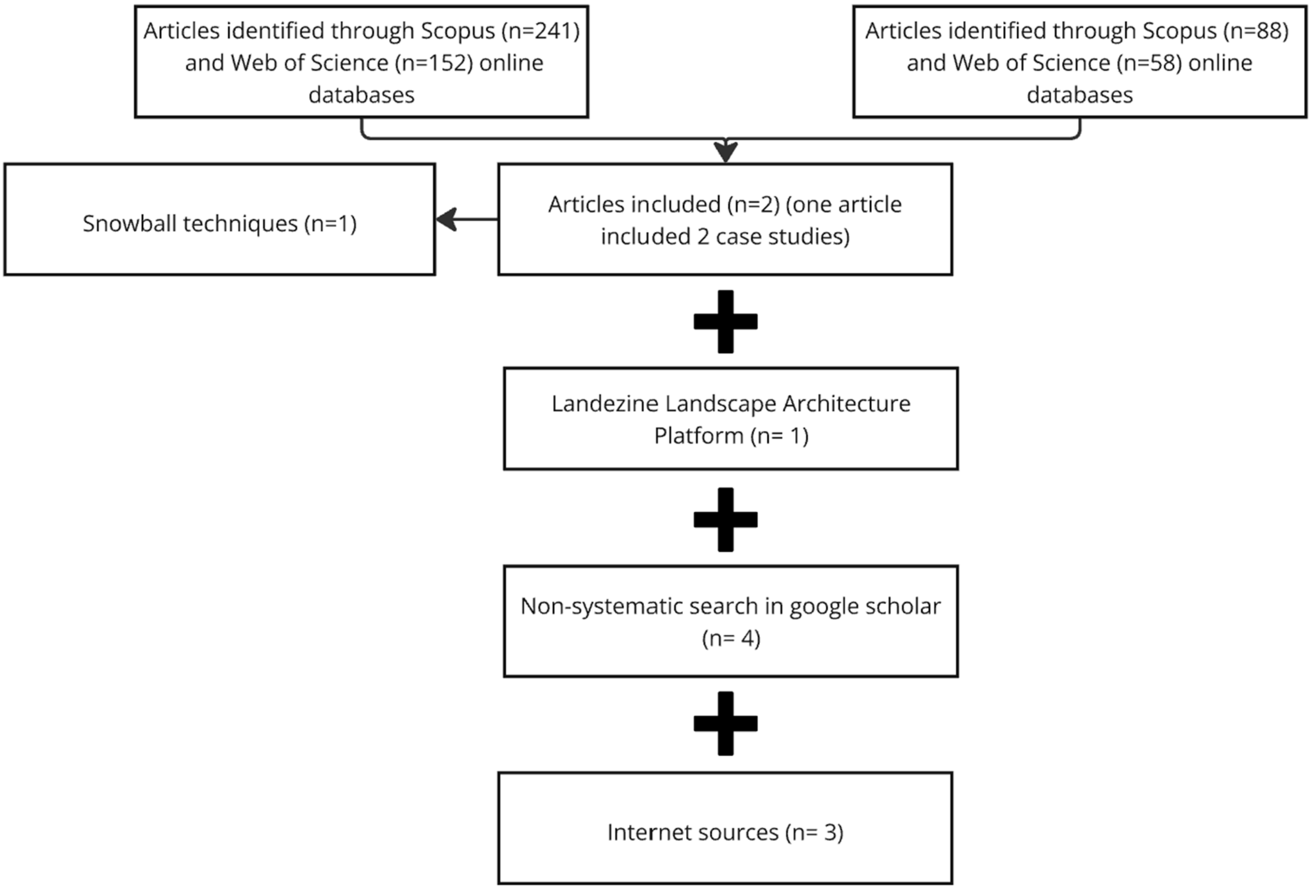

Figure 1. Scheme of the literature search for the case studies.

2.2. Identification of the Topographical, Social, and Climatic Conditions for the Implementation of Floodable Parks

The case studies were analyzed, and the topographical, social, and climatic conditions required for the implementation of floodable parks were evaluated. These were categorized in a systematic way to standardize the main drivers across the different case studies.

2.3. Identification of Key Elements for the Design of Floodable Parks

Key elements were identified from the case studies' designs and standardized across the case studies. Attributes were categorized into "water management elements", "recreational elements", and "biodiversity elements". "Water management elements" were further classified into "aNbS elements", "technical elements" and "water reuse". Within "biodiversity", a differentiation was made between "nuisance species management" and "promotion of biodiversity". These key elements complemented the processes of the conceptual model.

2.4. Identification of ESs and Benefits Delivered by Floodable Parks and the Association of These to the Identified Key Elements

According to the ESs classification of the European Environment Agency (EEA) (Classification of ecosystem services (EEA) (UNCEEA/5/7)), the benefits provided by the floodable parks were standardized and categorized into "provisioning", "regulating" and "cultural" ESs. These were further divided into the corresponding proposed classes by the EEA [26].

2.5. Identification of Processes and Influencing Factors Occurring in Floodable Parks

The studied processes are of a hydrological nature. Although a former study [27] has separated the main attributes supporting water circularity in NbSs into (1) the layer of plants and roots and (2) the body of water and its bed, processes taking place in these compartments were described jointly due to their interconnected relation. The identified processes occurring in aNbSs were pre-classified into "water detention and retention processes", "water purification processes" (later divided into "physicochemical water purification" and "biological water purification"), and "water reuse". This step resulted in a total of four processes considered for the conceptual model.

In order to identify these processes, a literature search was performed using the Scopus and Web of Science databases and filtered by title, abstract, keywords, and all fields, respectively. The following string was used for the period of 2000 to 2024: "retention pond" OR "detention pond" AND urban OR city AND "water quality" OR "water pollution" OR "water storage" OR "water reuse" OR "water purification" OR "water treatment" AND pluvial OR runoff OR rain. Through snowball techniques, using the references of the obtained papers, the literature review was completed (Figure 2). The sources of these papers can be found in Appendix A (Figure A1).

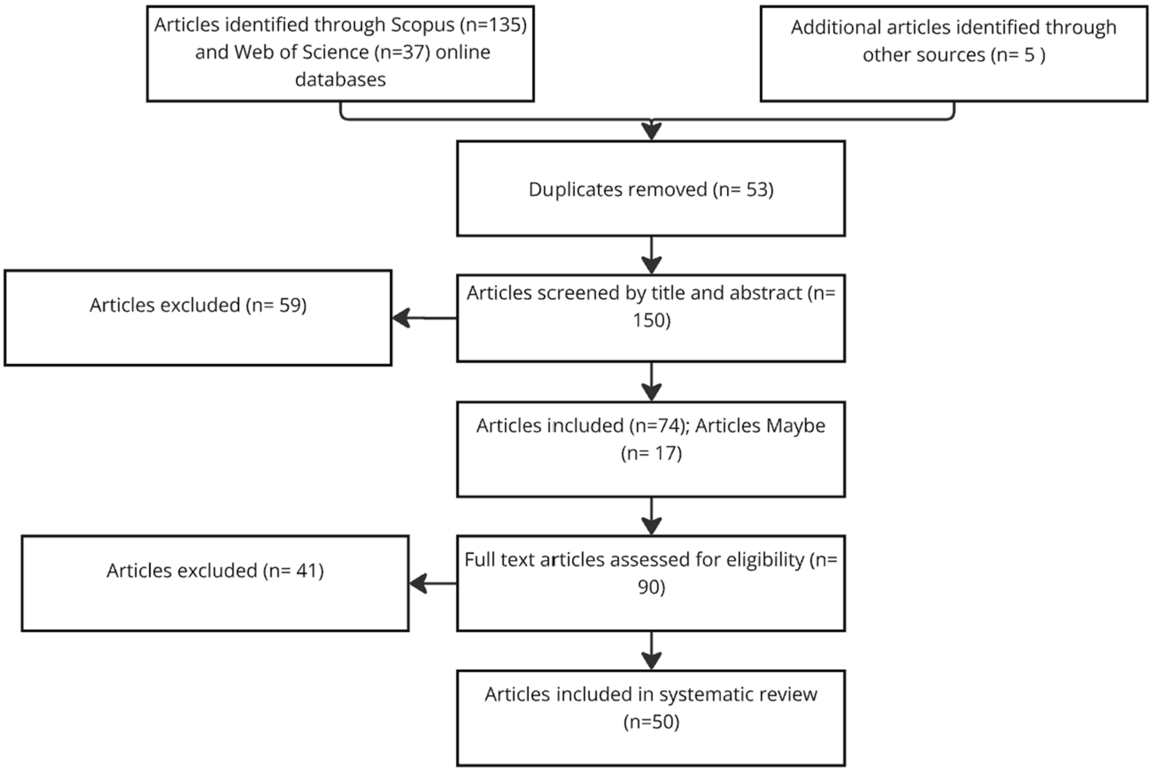

Figure 2. Scheme of the literature search for the processes occurring in floodable parks.

2.6. Development of the Conceptual Model

Based on the design characteristics of the floodable parks (e.g., arrangement of the modules, presence of wetland habitat, overflow possibilities, etc.), the processes and the identified ESs, a conceptual model was developed.

3. Results

3.1. Case Studies

Out of the 12 studies, four were found in Spain, one in Mexico, one in Norway, two in Denmark, one in the Netherlands, one in the United States, one in Taiwan, and one in Brazil. Although most of them were already built, two of them (i.e., Los Alcázares and La Quebradora) were still in construction and another two (i.e., Hans Tavsens Park, Celso Peçanha) were not implemented yet. An overview of the main design features of the selected parks is shown in Tables 2 and 3.

Table 2. Comparison of main drivers, functioning, and biodiversity incorporation of the selected case studies.

Name	Country	Drivers	Description of the System	Treated Water Reuse	Biodiversity
El Recorral Forest Park	Spain	Runoff water was reaching nature parks. There was a need for water discharge points for treated wastewater	1. Upstream tanks for first flush water storage and conveyance into treatment water 2. When tanks are filled, the park acts as an intermediate discharge point 3. Staggered ponds with design that enhances water purification 4. Water from the ponds descends to natural ravine where discharge is authorized	• Irrigation (i.e., parks, gardens, golf course) • Fire extinguishment • Street cleaning • Pond's filling	• Autochthonous vegetation • Creation of areas for nesting, feeding and refuge zones for amphibians and birds, • Insectivorous species such as bats and birds are attracted for biological pest control
Los Alcázares	Spain	Landscape modification (urbanization and agriculture) enhanced runoff water and its accumulation into unwanted discharge points (i.e., roads, sea).	1. Runoff water conveyed to the park's pond 2. When filled, water flows into channels along the park 3. When overflowed, the rest of the park is flooded gradually 4. If the maximum volume for storage is exceeded, water goes to a spillway 5. The park is designed with permeable zones to enhance infiltration 6. Additional water storage in an onsite tank	• Water reuse for internal irrigation of the park green zones after treatment	• Autochthonous xeric vegetation • Trees for shadow • Creation of areas for nesting, feeding and refuge zones for amphibians, birds, insects and bats • Insectivorous passerine birds for biological pest control • Bee hotel
Via Parque	Spain	Existing infrastructure was observed to be insufficient to hold runoff water from heavy rain events	1. Upstream tank (insufficient storage volume) collects first flush runoff water and conveys it to a wastewater treatment plant 2. Rest of runoff water/rainwater fills the pond gradually 3. The park is designed with permeable zones to enhance infiltration 4. Pond's biologically purified water is infiltrated into a below-pond tank for direct water reuse or soil water recharge 5. If it does not meet water quality standards, water is conveyed to wastewater treatment plant 6. After maximum flooding level of the pond, water goes to spillway 7. Design of park with permeable zones to enhance infiltration	• Irrigation of the park, city greenery and University Street • Street cleaning • Cleaning of onsite tank	• Permanent and temporary water zones to create different niches for biodiversity • Vegetation selection for water purification • Aeration to avoid toxic algae blooms
La Marjal	Spain	Natural ravines transformed into urban areas, resulting on small rain events causing high water accumulation. Existing tank observed to be insufficient.	1. Upstream existing tank 2. When filled, water goes to the park 3. Gradual filling of the park 4. When overflown, water goes to an underground tank 5. If water storage is exceeded, water goes to spillway 6. Water is conveyed to wastewater treatment plant	• Irrigation of the park • Aquifer recharge	• Constructed Wetlands (CWs) • Aeration to avoid toxic algae blooms • Creation of areas for nesting, feeding and refuge zones for amphibians and birds • Insectivorous species such as bats and birds are attracted for biological pest control

Table 2. *Cont.*

Name	Country	Drivers	Description of the System	Treated Water Reuse	Biodiversity
La Quebradora	Mexico	Water shortage, floods in urban areas due to landscape modification and lack of green areas.	1. Runoff water is collected in upstream tanks 2. When filled, runoff water is conveyed via existing piping network into the park 3. The spiral pond gradually fills 4. When the capacity for water retention is exceeded, water goes into a sport area with permeable surface 5. A concrete skate park with slope is gradually filled as well 6. There is an extra tank within the park in cases the storage volume is exceeded 7. Water is conveyed to the onsite wastewater treatment plant The park is designed with permeable zones to enhance infiltration	• Aquifer recharge	-
Hans Tavsens Park	Denmark	Runoff water caused damages to urban infrastructure and was discharged into a natural lake	1. Water flows from upstream urban areas to the park 2. Existing drainage system collects first flush water and conveys it to wastewater treatment plants 3. Park fills gradually 4. The park is designed with permeable zones to enhance infiltration 5. Rain water is conveyed downstream along the main discharge street, which will capture the runoff water thanks to its redesign with permeable surfaces and tanks. 6. Before it reaches the natural lake, water is conveyed into Constructed Wetlands for its further purification 7. Water from the park and the lake is continuously pumped (even in dry periods) to a purification system 8. This purification system also treats first flush runoff water before discharge into the lake 9. In case of exceeded storage volume, the water is conveyed to the lake without purification	• Private irrigation of rainwater from tanks • Irrigation of the park • Soil water recharge	• Vegetation will be selected to decrease air and noise pollution and provide habitat for birds and pollinators • Constructed Wetland (CWs) for further purification
Celso Peçanha	Brazil	Extreme flood events caused infrastructure damages and discharged polluted water to the river system	1. Runoff water is conveyed to the park 2. This park is near a river, so in order to avoid fluvial flood, a one-way floodgate will ensure only rain water is conveyed into the park 3. Gradual filling of the park 4. The park is designed with different levels which can withstand different flooding thresholds. The infrastructure will be constructed accordingly. 5. The park is designed with permeable zones to enhance infiltration	-	• Vegetation will be planted in order to increase volume storage capacity

Table 2. *Cont.*

Name	Country	Drivers	Description of the System	Treated Water Reuse	Biodiversity
Maple Valley Park	Taiwan	Water shortage due to direct discharge into the sea.	1. Runoff water from upstream is conveyed to the park, entering through a gate opened via remote control 2. The park is designed with permeable zones to enhance infiltration	• Irrigation of the park	• The vegetation planted in the park has increased the city's green coverage by 28,000 m^2
Enghaven Park	Denmark	Existing infrastructure was observed to be insufficient to manage current rain events, leading to runoff accumulation in urban areas.	1. Runoff water from nearby roofs and houses flows to the park 2. The lowest part of the park (a dry detention basin) gradually fills 3. When the capacity is exceeded, the rest of the park (including permanent ponds) is filled gradually	• Irrigation of the park • Street cleaning	• 11,000 perennial autochthonous plants have been planted, acting as a stepping stone in the green corridor of the city
Elsa Eschels-son's Park	Sweden	High economic losses due to floods in the past decade.Need to incorporate multifunc-tional areas in a growing urban population.	1. Runoff water from nearby areas is collected in the stormwater pond 2. Pond fills gradually 3. When overflown, water is conveyed into the permeable area (where the water infiltrates) and to the concrete sports space (where the water is stored) 4. When the water storage capacity is exceeded, the water flows into a spillway	• Pond's infiltration is prevented to avoid contaminated water reaching the local aquifers	• Vegetation is chosen to provide habitat for biodiversity • Stepping stone in the green corridor connecting nearby forest
Benthemplein	Holland	Lack of water-regulating practices in the neighbour-hood.	1. Rainwater flows to the stormwater management basins 2. Water is infiltrated and drained through gutters into the soil and waterway	• Soil water recharge	• No vegetation
Sidwell Friends School	USA	Integrated Water Management education	1. Rainwater falls from the roof to the park, which is filled gradually 2. The water flows through the vegetated terraces to the pond and underground cistern 3. Runoff water goes into settling tanks 4. The water from the tank and cistern is pumped to the upper terraces for its biological purification and infiltration 5. This cycle is repeated five days before the water is reused	• Toilet flushing • Pond's refilling during dry months	• Constructed Wetlands • Nature is an important element of this system, where 50 native plant species attract birds and insects.

Table 3. Comparison of main water management features of the selected case studies.

Name	Country	Return Period (Years)	Total Area (m^2)	Floodable Area (m^2)	Pond Area (m^2)	Maximum Inundation Volume (m^3)	Ratio (m^3/total m^2)	Ratio (m^3/floodable m^2)
El Recorral Forest Park	Spain	-	-	-	-	5304	-	-
Los Alcazares	Spain	100	110,000	110,000	45,000	490,000	4.45	4.45

Table 3. *Cont.*

Name	Country	Return Period (Years)	Total Area (m^2)	Floodable Area (m^2)	Pond Area (m^2)	Maximum Inundation Volume (m^3)	Ratio (m^3/total m^2)	Ratio (m^3/floodable m^2)
Via Parque	Spain	3	16,045	6000	978.27	12,500	0.78	2.08
La Marjal	Spain	50	36,700	36,700	6674	45,000	1.23	1.23
La Quebradora	Mexico	500	38,470	24,085	13,985	67,000	1.74	2.78
Hans Tavsens Park	Denmark	100	6600	4000	-	18,000	2.72	4.50
Celso Peçanha	Brazil	50	700,000	22,856	-	-	-	-
Maple Valley Park	Taiwan	-	-	-	-	200,000	-	-
Enghaven Park	Denmark	100	35,000			22,600	-	-
Elsa Eschelsson's Park	Sweden	10	-	6600	4000	1540	-	0.23
Benthemplein	Holland	-	5500	-	-	1800	0.33	-
Sidwell Friends School	USA	1	-	-	-	-	-	-

3.2. Topographical, Social, and Climatic Conditions for the Implementation of Floodable Parks

The topographical, social, and climatic conditions of each case studied varied, highlighting the need to adjust NbSs according to a specific local context. However, some generalizations could be withdrawn from the case studies. Particularly, all mentioned the need to locate the floodable park in a landscape depression or lower plain to avoid the outflow of the water once it had been stored in the detention pond of the park. Geotechnical investigations were performed in each case to ensure that groundwater levels were deep enough and therefore, that potential seepages could not reduce the storage capacity of the pond. These investigations are also important to assess the type of soil, geology, and land stability prior to the construction.

When analyzing the conditions that drove the implementation of the floodable park, in 10 of the cases, the existing infrastructure used to mitigate flooding (e.g., tanks, pipes, treatment plants as discharge points) was evidenced to be insufficient, even if seven reported that the natural topography enhanced runoff. Landscape modification was also frequently observed, either by urbanization (66%) or by the alteration of the natural water flow (25%), showing how the modification of the natural topography enhances water runoff in cities. The presence of urban water runoff was mentioned in 66% of the cases, caused by the accumulation of high water levels in urban zones due to the occurrence of big (66%) or small (16%) precipitation events. A total of 50% reported traffic collapse or damage to infrastructure due to pluvial water-related hazards. A lack of flood-managed areas and unwanted discharge points each accounted for 16.66% of the reasons to build the floodable park.

Regarding the social context of the localities at which floodable parks were implemented, a lack of green space, lack of social space, unused land, and lack of sports facilities were mentioned in 58%, 25%, 25%, and 16.66%, respectively. Interestingly, two cases mentioned the success of the implementation of floodable parks in the past as a driver to build another floodable park in the municipality, showing the effectiveness of this aNbS in tackling extreme precipitation events. This implementation is normally driven by the willingness of the municipalities to apply sustainable measures, since in 50% of the cases reported, the local authorities increased awareness and funding for this type of projects.

Lastly, it was noticeable how little consideration was given to biodiversity as a reason for the implementation of the aNbS. Only 25% mentioned the lack of green zone connectivity within the urban matrix and only one case study mentioned the need for conservation of the former habitat (i.e., wetlands) as a driver for the construction of the floodable park.

3.3. Key Elements for the Design of Floodable Parks

The design of a floodable park is fundamental for its correct functionality and appropriate runoff water conveyance, retention, storage, infiltration, and drainage. The design can also deliver water quantity and quality regulation by managing the water system's hydroperiod, choosing an adequate pond bed, integrating certain plant species, and avoiding stagnation of the water. However, the services delivered by floodable parks are not restricted to hydrological climate-related problems and therefore, they have to be designed for a broad variety of purposes. The concept of multifunctionality has been recently studied regarding the design of NbSs, since these are meant to address social, economic, and environmental issues simultaneously [28]. Key elements from the designs of the case studies were identified and categorized into "water management elements", "recreational elements", and "biodiversity elements".

3.3.1. Water Management Elements

Aquatic NbS

Within the parks, the most prominent water management elements were permeable vegetated zones and pavements (66%). In fact, three case studies mention the integration of other NbSs (e.g., rain gardens and vertical gardens) within the design of the park. For example, dry retention ponds (25%) and artificial wetlands or wetland mimicking systems (58%) were incorporated in the case studies; 33% acknowledged the enhancement of biological purification.

Technical

A great proportion (83%) of the floodable parks allowed the gradual filling of the park by favoring high percolation, controlling water through channels, or by constructing a terraced design. A total of 66% of the parks connected upstream collectors, tanks, and pipes (either already existing or built for the purpose), although only 25% mention the use of an emergency spillway for safe overflow when the storage capacity is exceeded. Interestingly, 41% of the floodable parks incorporated a tank inside of the park which could be placed below the pond or next to it as a backup in case of the overflow of the pond. Also, 33% of the ponds integrated a pump system to increase aeration to prevent water stratification, and a 16% used mechanisms to avoid the deposition of suspended particles. The flooding was mentioned to last less than 48 h only in two case studies for which the full construction proposal was obtained, but we believe this can be generalized to the conceptual model of a floodable park [29].

Technical elements such as dikes, dams, and smart systems, as well as erosion and landslide prevention elements were also considered in the design of 41% of the floodable parks, although only 16% reported using existing infrastructure (i.e., tanks or the pipe network). The pond's bed was not specified in most of the cases, but discrepancies in the material and design used were found (e.g., reticular permeable material (25%) vs. impermeable bed (8%)).

In addition, differentiation between polluted (first flush) and non-polluted water was performed in 33% of the case studies, discharging the water at different authorized locations depending on the water quality.

Water Reuse

Regarding water reuse, 91% reported the reuse of treated water, either using the treated water for internal uses (i.e., irrigation of the park (58%) or pond recharge (33%)), or using this water for external uses, either irrigation (i.e., public green spaces) (16%) or street cleaning (33%). This water was also used for aquifer recharge in 25% of the case studies. One of the case studies mentioned the reuse of water for fire extinction.

3.3.2. Biodiversity

Promotion of Biodiversity

Interestingly, 66% of the case studies chose a wetland mimicking system within their ponds, and 41% favored the growth of riparian vegetation in the pond perimetry by controlling the O_2, nutrients, and sediment and reducing contaminants. Rendering a place for biodiversity was also considered in the design of the floodable parks: 33% placed nesting zones for birds, 16% gave space for amphibians, and 16% built pollination sites.

Regarding the selected vegetation, 41% of the case studies chose autochthonous plants and 16% mentioned avoiding invasive species. In 16% of the cases, rain-fed species were favored as well as those which had ecological value and the capacity to prevent erosion. However, just one mentioned the incorporation of flood-adapted species. Interestingly, one case mentioned taking measures (i.e., extensive management and gradients) for enhancing a heterogenous hydroperiod. While promoting biodiversity, 33% of the case studies mention the functionality of the vegetation (i.e., shadow, noise reduction, and aesthetic value) and 25% the creation of stepping stones in the city's green corridor, which shows how the design, the ES delivery, and the support for biodiversity are deeply intertwined.

Nuisance Species Management

Mosquitoes and toxic algae blooms are often a trade-off of the incorporation of stagnant water elements within cities. Therefore, floodable parks should be managed to decrease the presence of nuisance species. Mentioned management strategies for decreasing mosquito populations were the introduction of insectivorous animals (e.g., mosquitofish, bats, and birds) (25%) and the selection of vegetation which attracts predators of mosquitoes and other pests (8%). Regarding the prevention of toxic algae blooms, aeration is favored through the integration of a cascade of fountains in the design (8%), as well as the use of ultrasound emissions for O_2 production (8%) and circular water pumping (25%).

3.3.3. Recreational Elements

Recreational elements in floodable parks were not found to differ much from regular urban parks. Sports facilities were incorporated in 75% of the studies, game spaces and resting places in 33%, and picnic areas and a lecture zone in 16%. However, some elements in their designs highlight the multifunctional character of these parks, such as the presence of educative posts (50%), community gardens (41%), viewing points for contemplation and elevated corridors (41%), connection with other green areas of the neighborhood (25%), and the integration of cultural elements (25%). Existing features (e.g., church, school, and rivers) were used in three of the case studies as the framework of the project. One floodable park included a commercial zone within the park and another a pavilion or auditorium for performances. Another case study mentioned the use of the park as a botanical garden for educational purposes. However, in only two were mentioned the inclusion of warning elements so citizens could leave the park before major flooding. One case study mentions the use of floodable recreation infrastructure.

3.4. ESs and Benefits Delivered by Floodable Parks and the Association of These to the Identified Key Elements

None of the analyzed case studies used the concept of ESs to describe the floodable parks, although three mention the concept of NbSs. The innovation of this paper is to undertake an ESs perspective which could be used to compare and frame floodable parks together with other well-studied NbSs (e.g., green roofs, vertical gardens, bioswales, artificial wetlands, etc.). Therefore, the depicted benefits were translated into different ESs according to the EEA [26].

The main ESs, mentioned in 91% of the case studies, was water regulation. Recreation and community activities also played an important role as a service delivered by floodable parks, accounting for another 91%. Knowledge and educational value were highly considered, as 66% of the floodable parks incorporated informative panels or activities (e.g., tours and teaching) in their design in order to raise awareness about water-related hazards. Heritage services were delivered in 41% of the cases. Despite not being a main reason for implementing the floodable park, biodiversity as a benefit was mentioned in 66% of the case studies. A total of 25% of the parks highlighted the potential improvement of mental and physical health which can be obtained in these parks. Aesthetic value, social connection, and a connection to nature were described as benefits in two of the parks respectively. Remarkably, climate regulation, air purification, and noise reduction were not core services for which these parks were constructed. Lastly, although this aNbS can be connected to treatment plants for water reuse, only two case studies mentioned water circularity as a service that these parks can offer.

3.5. Processes and Influencing Factors Occurring in Floodable Parks

Floodable parks are aNbSs which normally rely on the presence of a retention pond in order to accommodate the excess of runoff water. Meanwhile, they provide additional benefits (aesthetic, recreational amenities, groundwater recharge, sub-potable water supply, and new habitats for wildlife). After the review of the case studies, it was observed that the retention pond acts as the main water-regulating element of floodable parks. Processes occurring therein were classified into (1) water detention and retention processes, (2) water purification processes, and (3) water reuse. However, there was no detailed explanation of how these processes allowed the ecological functioning of the floodable park, and therefore, these were further investigated through a second systematic literature review. Both the biological and physicochemical components of the three hydrological processes are described below, according to their respective states of the art obtained from this second review.

3.5.1. Water Detention and Retention Processes

One of the most important features to consider when designing the detention/retention pond (hereafter called pond) within a floodable park is the water residence time [30]. This has been recommended to be between 24 to 48 h by institutions such as the EPA and water agencies [31,32]. Ponds are designed to gradually release runoff water into downstream aquatic ecosystems via horizontal flow, thus decreasing potential downstream soil erosion and flooding. However, when the water residence time is not correctly determined when designing these ponds, runoff water cannot be efficiently discharged and is held for a longer time than required. This causes the water to rise beyond the designed level, eventually producing higher pond outflows [33].

Three factors of pond design are crucial for a pond to correctly manage excess water. The first factor is the distance between the inputs and outputs, which has to be maximal in order to allow the water to flow and sediments to settle [34]. The second is the correct orifice size of these inputs and outputs. Orifice size has to consider the fluctuations of the runoff inflow and discharge, as well as the pond drainage rate [33,35–37]. The third feature of stormwater management practices is size [35,37,38]. Water retention efficiency relies on a sufficiently large area (2–5 % of the watershed area) [39] which can hold the runoff water below a certain depth (i.e., 1.5–3 m) [33,37,40]. In fact, small surface pond areas hinder mixing occurring by the wind, causing stratification and reduced water residence time, which results in ecological damage and increased greenhouse gas [36].

Another parameter which determines the water retention is the permeability of the pond's bed [35]. The higher the permeability (e.g., sandy silt, gravel and sand), the higher the groundwater–surface water interactions and the higher the water residence time [36]. It is of foremost importance that the pond's bed remains uncompacted and that proper maintenance (i.e., removal of leaf litter, revegetating bare areas, and the minimization of soil disturbance during construction) is performed [35].

The imperviousness of the surroundings also influences the performance of wet detention ponds. Urban aquatic ecosystems are usually subjected to rapid increases and decreases in water levels (i.e., flashy hydrology) due to a lack of permeable surfaces. Therefore, infiltration and evapotranspiration of the surroundings are two main processes that determine the correct performance of retention ponds [33]. Infiltration and evaporation within the pond also condition the water residence time.

Lastly, the water residence time determines not only the flow attenuating efficiency, but also other processes such as water purification (see Section 3.5.2). The longer the residence time, the more effectively coarse particles and particulate-bound pollutants are removed via gravity sedimentation [30,34–36,41] and the more time biological communities have to degrade or uptake these contaminants [30]. Therefore, longer retention times have been found to promote more adsorption, while higher groundwater seepage rates have been linked to microbe export from biofilters, decreasing removal efficiency [42].

The water residence time conditions the species living in the pond as well. Slower rates of water level decline have been positively correlated to native obligate tree and native shrub coverage [33].

3.5.2. Water Purification Processes

Urban aquatic ecosystems receive incoming runoff water from their surroundings. This water carries various sources of nitrogen and phosphorous (e.g., fertilizers, lawn and garden waste, and pet waste) and minerals (e.g., calcium and sodium bicarbonate), which respectively increase nutrient loadings as well as pH and conductivity. This consequently changes the soil and sediment's chemistry and the present biological communities [41]. Other pollutants found in the runoff water include suspended solids (e.g., erosion and litter), hydrocarbons (e.g., fuels), metals (e.g., roads), and even fecal coliforms (e.g., humans and animals) [43–45]. Wet retention ponds have been demonstrated to significantly remove contaminants apart from attenuating the runoff peak [43,46].

Physicochemical Water Purification

Pollutants of different natures are removed from the water by precipitation or binding to sediment particulates and soluble organics (i.e., heavy metals) [47,48], adsorption and ion exchange via soil filtration (i.e., ammonia and phosphorus) [35], volatilization (i.e., NH_3 and hydrocarbons) [27], and photochemical oxidation (hydrocarbons) [43]. The physicochemical water purification focuses mainly on the processes of sedimentation and filtration, by which organic matter, metals, and suspended solids are deposited and trapped in the sediment layer and in the infiltration substrate, purifying the water [34,49]. Other physicochemical processes that occur in these ecosystems are straining, mixing, dilution, and aeration [49].

Pollutants in the runoff water include (1) dissolved pollutants and (2) pollutants associated to sediment particles that accumulate in the waterbody's bed. Different processes are required for the removal of each type of pollutant. While sorption and biodegradation (see Section "Water Detention and Retention Processes") are the dominant processes for eliminating soluble pollutants like biocides and pharmaceuticals [50], sedimentation is the primary physicochemical mechanism by which pollutants are removed from the water column [37,43,44]. According to the EPA, retention ponds have a removal efficiency of 70–90% of total solids, 50–70% of total phosphorous, 30–50% of total nitrogen, and 50–80% of metals [51].

The efficiency of sediment removal depends on factors such as the type, size, shape, and density of the soil particles [50]. Vopicka (2009) [43] found that, contrary to sand, silt and clay are positively associated to metal and heavy-end hydrocarbons due to the negative charge of clay particles to which these contaminants adhere. The size of the clay particles is also relevant, since pollutants concentrate in clays with smaller particles. This should be considered in the design of the pond, since sand normally deposits on the inlet and more loamy soils (with contaminants) may accumulate further in the pond, where dredging is more difficult.

Factors such as temperature can decrease the efficiency of the removal. In the study of a novel solution consisting of chained bioretention cells and a retention pond, Pineau et al. (2021) [46] reviewed the effect of temperature on metal removal and concluded that, although with sufficient percolation capacity, the temperature should not affect total metal removal, the removal of some heavy metals (e.g., zinc (Zn), lead (Pb) decreased with a lower temperature. Also, they observed that the influx of de-icing salts alters the transformation of metals in the soil of bioretention and retention ponds, increasing their dissolution in water and discharge in the efflux. However, the negative effect of salts on the removal of metals in submerged conditions was lower compared to the unsubmerged conditions of the bioretention cells, which highlights the importance of the permanent water presence of retention ponds.

Biological Water Purification

Although sedimentation can remove coarse and heavy particles with attached pollutants, biological processes are required to remove lighter particles and dissolved fractions [44]. These fractions are usually the most nutrient-rich and contain high metal concentration [37]. In addition, already settled matter and retained nutrients might, over time, be released from the pond, due to wind mixing, mineralization of organic particles, and/or transformations into a reduced state. Therefore, biological purification should be encouraged.

The biological component of ponds entails mainly microbial and vegetative processes [44]. Three major pollutant removal mechanisms are (1) nutrient uptake, (2) microbial decomposition and breakdown of organic matter on floating mats and plant root systems, and (3) filtering of sediment and associated pollutants by root systems [52]. Biological water purification also includes processes such as oxygen transfer [53].

The microbial mineralization of organic elements (phosphorus, nitrogen, and carbon) allows the energy and matter transfer to the primary producers [54]. In fact, phosphorous removal relies mostly on uptake by vegetation. Phosphorus transformations (e.g., from unreactive to reactive forms, and from dissolved into particulate forms) determine its bioavailability and therefore the phytoplankton and plant uptake capacity [55], showing how deeply intertwined purification processes of different natures (e.g., physicochemical and biological) are. Dissolved inorganic nitrogen species, especially ammonium (NH_4^+), are considered the most available for immediate assimilation by aquatic microorganisms and plants. However, this uptake is often seasonal, and the stored nutrients are released as dissolved and particulate organic nitrogen after senescence. Long-term removal of nitrogen includes biological processes such as ammonification (mineralization of organic nitrogen into ammonia and ammonium, NH_3/NH_4^+), nitrification (oxidation of NH_3/NH_4^+ into nitrate, NO_3^-), and denitrification (aerobic reduction of NO_3 into nitric oxide (NO), nitrogen gas (N_2) and nitrous oxide (N_2O) [47]. On the other hand, hydrocarbons can be biologically degraded through processes such as fermentation and aerobic/anaerobic respiration, although due to the hydrophobic nature of the latter, sedimentation and sorption of particulates dominate as the main removal mechanism [43,44].

Benthic infauna also influence biogeochemical cycles and nutrient flux directly through feeding, respiration, secretion, and excretion, and indirectly through bioturbation, bioirrigation, and resuspension [56]. These processes alter the redox potential and oxygen content in the soil (creating oxic and anoxic zones), promote solute exchange, and contribute to the sequestration and transformation of nutrients and carbon [56]. They can also alter the biotic component of the sediment by feeding on microbes and introducing gut bacteria through excretion.

An important influencing factor in these processes is the oxygen content in the water and sediments, since aerobic and anaerobic bacteria target different pollutants and act at different biodegrading rates. In aerobic ponds, algae growth can increase the oxygen in the water column, which is later consumed by aerobic bacteria [27]. Oxygen content in the water and sediment can be altered through the modification of the water residence time, the type of aNbS (e.g., vertical versus horizontal flow constructed wetlands) and the presence of plants.

Vegetation can be used as a phytoremediation technology to reduce, degrade, and immobilize environmental toxins and thus restore the area [35]. Plant roots embody the most important treatment component of the vegetative system. In fact, it was found that nutrient removal was highest in ponds that had maximum contact with plant's rhizomes [34]. The roots not only uptake contaminants, but also provide an environment where microorganisms can perform their biodegradation processes (e.g., denitrification for N removal) [34,57]. Therefore, the roots and biofilm perform adsorption, absorption, and uptake processes in ponds, contributing to its purification.

The efficiency of plants as pollutant removals depends on their size, species, and root mass. Floating wetlands have been studied to enhance nutrient uptake through assimilation and promote nitrogen removal via denitrification; emergent aquatic plants can decrease phosphorus, and submerged aquatic plants are better for decreasing minerals and therefore the pH in the pond's water [41]. Macrophytes with voluminous root systems (e.g., *Phragmites australis*) have been recommended for water-based NbSs such as ponds and constructed wetlands [58], and therefore can be applied for floodable parks as well. Other species that can be used for this purpose are, e.g., *Carex virginata* and *Juncus edgariae*, since they have been observed to develop greater biomass than other species (e.g., *Eleocharis acuta* and *Schoenoplectus tabernaemontani*) and accumulate metals present in the runoff water. The contaminated biomass can be later removed via regular harvesting. To this end, Floating Treatment Wetlands (FTWs) show an advantage compared to regular Constructed Wetlands (CWs), since the latter requires a complete excavation of the soil which is a rather invasive operation [59].

3.5.3. Water Reuse

Water scarcity is another of the consequences of climate change. The growing human population exacerbates water stress by increasing water demand and groundwater abstraction. In the past decade, stormwater reuse has been considered in urban areas in order to more efficiently utilize the available water resources [60,61]. Different aNbSs, such as artificial wetlands, permeable surfaces, bioswales and rain gardens have demonstrated their capacity for water treatment and purification for its subsequent reuse [61]. However, further treatment is needed for the utilization of stormwater infiltrated and retained in the retention ponds. Several impediments hinder its reutilization, like the aforementioned presence of oils, litter, heavy metals, nutrients, sediments, organic matter and bacteria, which may persist despite the physicochemical and biological purification [61–63]. Pathogenic microorganisms have been identified as the main concern regarding stormwater reuse, since it directly impacts human health if users have contact with untreated urban stormwater [63].

Natural disinfection through processes such as filtration, sedimentation, dehydration, and sun irradiation can provide a certain level of runoff treatment. However, the removal of pathogens achieved by NbSs does not reach the national standards of EU countries in which floodable parks have been implemented (e.g., Spain). In addition, although natural filtration can remove fecal bacteria, this might percolate into the groundwater [45]. Further disinfection by UV, chlorination, or ozonation is a necessary final step before the reuse of reclaimed water [27]. Certain elements can be included in the design of the aNbS, such as biofilters, sand-gravel filter [38], biochar, and real-time control (RTC) [37], in order to increase the suitability of the water quality for harvesting and reuse [61]. Once treated, the water can serve multiple purposes such as irrigation, cleaning and cooling of public spaces, fire hydrants, replenishment or development of artificial lakes, and even potable water [61]. Ponds can also act as a potential reservoir of treated water [61] and collected rainwater can be used directly, since the level of pathogens is considered lower, and therefore its quality is good enough without any further treatment [64]. Nevertheless, risk management and financial assessment for stormwater reuse is needed for the upscale of this type of solution.

Furthermore, retention ponds have also been studied for energy recovery using the stored volumes after urban floodings. However, the efficiency of this system for this purpose depends on the total runoff, the timing of the runoff, and the topography and geometry of the retention pond. Thus, this type of water reuse is usually recommended for countries with abundant rainfall [65]. Low heads (small waterfalls or systems with non-negligible flows) require hydropower converters with significantly low costs of installation and maintenance, although the higher the head, the better the production of energy (for the same volume). A threshold volume is required for the system to operate correctly and design considerations (e.g., outlet diameter) can alter the efficiency [65]. Nevertheless, Ramos et al. (2013) [66] investigated a retention pond in which 210 MW h/year could be produced (for an average year hourly power of 800 W).

3.6. Conceptual Model of Floodable Parks

A conceptual model was developed after the identification of the main processes and key elements of the design and its relationship with the ESs delivered by the floodable parks of the case studies (Figure 3). Although the main attribute of the floodable parks was usually a permanent water body, the surrounding vegetation (where in fact other NbSs were incorporated, such as rain gardens, vertical gardens, or dry detention basins) and paved surfaces (i.e., permeable pavements) were fundamental for the correct functioning of the floodable parks. Wetland mimicking systems were incorporated in most of the reviewed cases, supporting the identified (and further reviewed) processes that take place within a retention pond.

It was observed from the case study review that water retention and water purification were intimately related to the presence of an aNbS, which allowed the gradual filling of the park by enhancing water infiltration. However, aNbSs were not enough, so technical elements were implemented (e.g., upstream or onsite tank, dams or erosion-prevention mechanisms, channels and pipes, smart systems for water circulation, or a reticular pond bed) to further reinforce and improve the water retention and water (physicochemical) purification processes.

The final aim of these processes was the subsequent water reuse. Thus, water from the tanks and water from the ponds (either being first forwarded to a treatment plant or not) was used for internal or external uses. Internal uses were normally the irrigation of the vegetation of the park and the recharge of the pond itself, while external uses included irrigation of public spaces, street cleaning, and fire extinguishment. Water reuse, despite not being a tangible element as the aNbS and technical elements described above, was key to the design of the reviewed floodable parks, and therefore, was included by the authors in the conceptual model as part of the water management of the parks. Water reuse was found to be linked to the process of water retention, since this determines the availability of water for other uses, and most importantly, water purification (biological and physicochemical). However, for this water to be utilized, normally a further treatment was needed to reach the quality standards for the aforementioned uses so the water was conveyed to wastewater treatment plants.

All the abovementioned elements and processes contributed to the water-regulating ecosystem service delivery of the park.

Moreover, biodiversity was a key element of the floodable park design. Biodiversity, which was supported in the different aNbSs of the park and in the pond, has been studied to favor water regulating processes, as described in Section "Biological Water Purification". Hence, it should be promoted by the selection of the correct vegetation species (i.e., autochthonous, non-invasive, climatically-adapted, and supporting water regulating processes) and the creation of refugia (i.e., nesting places and pollination sites), which increase the biological connectivity of the city. This enhancement of biodiversity was observed in most of the case studies. On the other hand, flooding might increase the presence of nuisance species (i.e., mosquitoes and toxic algae). Therefore, different attributes were used in the floodable parks to reduce them. Natural attributes included the attraction of insectivorous species for biological control, whereas technical attributes were water circularization and ultrasound emissions for increasing O_2 concentration in the water. Biodiversity was portrayed in the conceptual model both as a co-benefit and a disservice, since it promotes services but can potentially affect human health through the increases of these species.

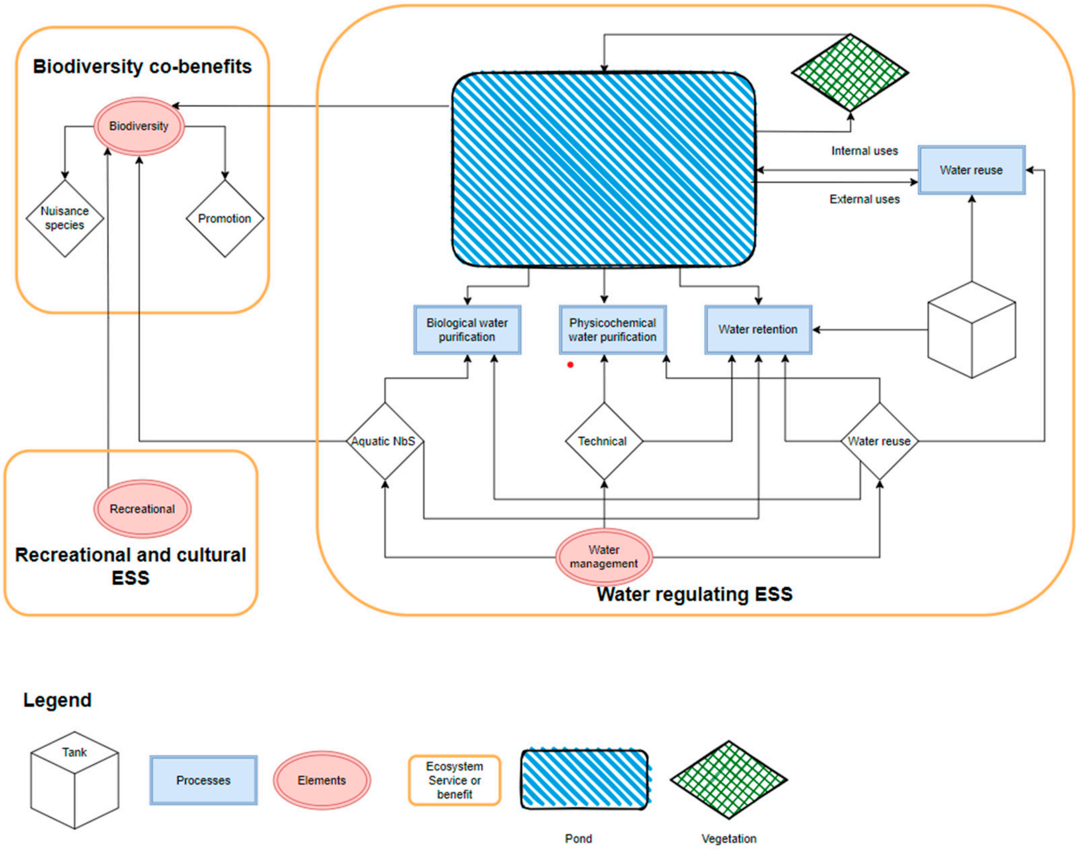

Figure 3. Conceptual model of a floodable park. The blue striped rectangle represents the pond and the green checkered diamond the permeable surfaces present in the park. The chosen processes are represented as blue rectangles, the identified key elements of the design of floodable parks are represented as red circles, and further divisions of both are represented as white diamonds. A water tank is shown as a cube. All these elements are grouped according to the main identified ecosystem services. Connections between each other are represented with arrows.

Biodiversity was interconnected with recreation elements in our model. For example, vegetation was used for several purposes (e.g., shadow, noise reduction, and air purification), which improved the conditions for relaxation, sports, and leisure. Connectivity with other green areas of the neighborhood increased the spatial transference of these services. On the other hand, biodiversity also promoted cultural and social services through the creation of educational and community gardens. Floodable parks had to incorporate recreational elements in their design, which are adapted to inundation. These were, for example, elevated corridors or floodable infrastructure. Also, warning systems warned citizens to leave the park before a major inundation.

4. Discussion

Humans have altered the natural topography of landscapes in such a way that common meteorological phenomena such as precipitation are now recurrently causing disruptions in our society. Urban areas have been designed to discharge pluvial runoff but, as it was found in the review of the case studies, existing water management infrastructure is currently not capable of withstanding the increasing volumes of longer and more frequent extreme precipitation events. Therefore, it has recently been acknowledged that, instead of building our metropolises to be impermeable, cities have to start welcoming water into their designs. This need is reinforced by the effects of the opposite climatic impact of global change, drought. Water is becoming a scarce resource and thus, any opportunity for reusing it needs to be undertaken.

Floodable parks are a novel solution which were conceived within this new conception of cities. In the introduction, these parks were defined as recreational spaces to which pluvial water is conveyed into a stagnant waterbody for its retention, infiltration, and drainage and which can be temporarily flooded. However, after the review of the case studies and the processes taking place within their floodable parks, noteworthy importance has to be given to the pervious areas that surround the permanent pond. Although they do not capture the main mass of water entering the park, these areas are fundamental for allowing the gradual filling of the pond and decreasing the peak flow volume which may otherwise be discharged downstream with fatal consequences. In our conceptual model, these pervious areas were pictured as vegetation, but they include several aNbSs such as dry basins, rain gardens, wetland mimicking systems and permeable pavements. Thus, floodable parks can be re-defined as "recreational spaces to which pluvial water is conveyed into a stagnant waterbody for its retention and drainage and which can be temporarily flooded as a result of the infiltration occurring in the surrounding aNbS".

These findings align with prior work on detention ponds, where it is recommended that detention ponds incorporate other stormwater control measures either (a) upstream of the detention pond (e.g., bioretention swales and other infiltration practices for water infiltration), (b) along the pond (e.g., forebays and vegetated buffer strips to decrease nutrient content in the water, sediment input, and water erosion), and (c) within the pond (e.g., floating wetlands to enhance nutrient uptake and nitrogen removal via denitrification) [41,54]. Hancock et al. (2010) [33] state that, amongst others (i.e., under-sizing), reduced infiltration and evapotranspiration hinder the correct functioning of retention ponds, sustaining the need for additional elements in their surroundings to improve their water regulation. They also write that the proportion of green areas around these solutions are frequently overestimated, which creates a mismatch between the calculated volume that the pond can hold and the observed one. Integrating other aNbSs in the surroundings of the pond would assure that the park can adequately manage current and future runoff by increasing the area in which the water is accommodated and thus, reducing the runoff peak flow and discharge through infiltration.

Several studies have demonstrated that retention ponds alone cannot meet the water-mitigating requirements. Hess et al. (2022) [41] studied stormwater wetlands which were either connected or not to detention ponds to see whether the discharge was slower when these two aNbSs were connected. Although the water level decline was 11% slower when both were connected, it was still 13% faster than non-urban wetlands, suggesting that detention ponds alone cannot recreate pre-development hydrological dynamics and thus lessen urban impacts on downstream ecosystems. Hancock et al. (2010)'s findings corroborate the results of similar studies in which retention ponds, regardless of their size and design, are observed to exceed the calculated outflows, again recognizing their inefficiency in reducing overall runoff volume to pre-development conditions. Thus, the surrounding of the pond by aNbSs is indispensable for the pond within the floodable park to function correctly. Further research on the processes occurring in floodable parks should be performed in order to understand, in an integrative way, the intertwined functioning of both the retention pond and the surrounding aNbSs.

Other studies have observed the inadequacy of retention ponds to remove the dissolved pollutants of the runoff water [47]. Although different elements (e.g., filters) can be incorporated into the design of the ponds in order to improve the retention of the dissolved pollutants [38], the microbial degradation and uptake of these pollutants by vegetation should be enhanced. Hence, biodiversity should be an intrinsic element within the pond's design. Many of the selected case studies incorporated a wetland mimicking system. Andradótir et al. (2014) [67] agree that ponds with wetland mimicking systems, such as those found in the studied floodable parks, are an ideal solution, since both the removal of particulate species through gravitational settling and the uptake of dissolved nutrient species by plants and algae take place. This is of foremost importance for those species and heavy metals (e.g., Zn and Cu) which have both dissolved and particulate phases and for which only physical methods are not sufficient [38,59].

Despite the advantages of incorporating natural elements in the design of aNbSs, it was observed in this study that it was normally not a factor driving the construction of the studied floodable parks. However, their incorporation provided benefits beyond water regulation (e.g., shadow, noise reduction, aesthetic value, and social interaction), increasing recreation and sense of belonging. These findings align with those of Jabbar et al. (2021) [68], who observed that UK citizens considered park trees important not only for aesthetic beauty and wildlife habitat but also for flood protection, pollution reduction and climate regulation, and 97.7% of them considered the biodiversity of trees essential in urban parks. However, the selection of the plant species has to consider both local climate adaptation and flood adaptation, which can be challenging in arid regions.

One proposed solution which may fit within the floodable park concept is Floating Treatment Wetlands (FTWs). FTWs, as their name indicates, are emergent macrophytes grown hydroponically on the surface of the pond. FTWs have several advantages over the traditional Constructed Wetlands (CWs), as McAndrew et al. (2016) describe [69]. In the first place, in CWs, the vegetation is rooted in the sediment, limiting the root exposure and therefore the nutrient capture. On the other hand, in FTWs, nutrients can be directly taken up from the water column. In the second place, the suspended root matrix of the FTW can provide a large surface area for the growth of biofilms where microbial transformations of pollutants (e.g., denitrification) can take place, and increase the sediment capture function by physically trapping suspended sediments and enhancing the flocculation and precipitation of particles. Despite these suspended roots occupying space on the water column, FTWs do not detract from the flood storage capacity of the pond, a main issue when designing wetlands within retention ponds [69]. In the third place, aerial and root tissues that have accumulated nutrients and pollutants can be easily harvested without damaging the benthic system of the pond. In the fourth place, shore-rooted vegetation suffers flooding stress and is prone to be flooded. However, the buoyant nature of the FTW allows water levels to change with no risk of threatening the plant's survival. This is especially relevant in the case of floodable parks and thus, it is suggested that it should be adopted in their design. One more advantage of FTWs is that they can be implemented inexpensively and on retrofitted parks, and therefore they can increase the performance of the urban ponds without significant land acquisition or earth removal [47,69].

In fact, one of the major challenges of urban planning nowadays is the lack of space for accommodating water and giving space to nature. One disadvantage of floodable parks is indeed their size. Other NbSs (e.g., green roofs and rain gardens) are often preferred to wet retention basins due to their easier and less costly implementation [27]. Therefore, retrofitting former urban parks into floodable parks should be considered as a way to optimize the available urban space. Of all 12 case studies, two parks, namely the Enghaven Park (Copenhagen) and Maple Park (Taiwan), were retrofitted from former urban parks, pioneering the upgrade of cities into more multifunctional spaces. Lourenço et al. (2020) [1] advocate for the multifunctionality of spaces in order to compact cities and increase their ecological performance. However, it is important to study the trade-offs that may arise between the different functions and services that these spaces provide.

Lastly, emphasis should be placed on the importance of water reuse, adding a layer to the multifunctionality of floodable parks. Floodable parks differ from other aNbSs in their intimate relation with water treatment facilities, as has been observed in this review paper. Tsatsou et al. (2023) [27] states that the circularity of NbSs can be enhanced through their integration with existing grey infrastructure, which treats water for its future reuse. Depending on its purpose of reuse, water quality standards vary. An interesting thought of this paper is to keep a certain concentration of nutrients in the water, since normally this reclaimed water is used for the irrigation of urban green spaces or urban agriculture, and thus the fertigation practices recycle these nutrients and reduce the need for additional fertilizer. However, this practice has the disadvantage that, since the fertilizers are not released slowly (as solid fertilizers are), there is an increased risk of the nutrients reaching the groundwater. The supply of water from floodable parks as a sustainable alternative of non-potable water is of high interest, but the practical details of such a connection (runoff areas, water quality standards, and technical design) should be better studied.

5. Conclusions

Urban areas are increasingly facing flooding which they are incapable of mitigating. The existing water management infrastructure is now frequently overflown (even under small precipitation events) due to the combined effects of climate change and urbanization. City design rarely incorporates permeable zones where runoff water can be infiltrated, nor gives enough space for water to be retained until it can be drained naturally. Floodable parks are unique solutions that combine stormwater management with natural processes to create a multifunctional space where water can be welcomed. This review of twelve floodable parks which were constructed for pluvial control gives insight on the rising needs for multifunctional recreational areas. The parks were constructed in low-land zones where both land modification and inadequate water infrastructure were exacerbating the impacts of floods. The parks were designed not only to serve for leisure, but also provide space for water retention and habitats for biodiversity. Remarkably, most of them were connected to treatment plants where the runoff water was treated for further reuse. This highlights the increasing importance of the utilization of all available water resources. However, it is of foremost importance to understand the trade-offs between the different functions provided by floodable parks in order to develop a design that can maximize its services and benefits. Our conceptual model revealed the need of incorporating vegetated aNbSs surrounding the main aNbS, the retention pond, in the design of floodable parks. Future research on the interdependency between these two types of aNbSs is needed in order to comprehend their mutual role on water runoff mitigation and purification. Cities have to adapt to the multiple challenges which global change is posing and will pose in the future, and floodable parks can help the transition towards more sustainable and resilient cities.

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Data Availability Statement: For the data supporting the reported results, contact the contributing author.

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

Appendix A

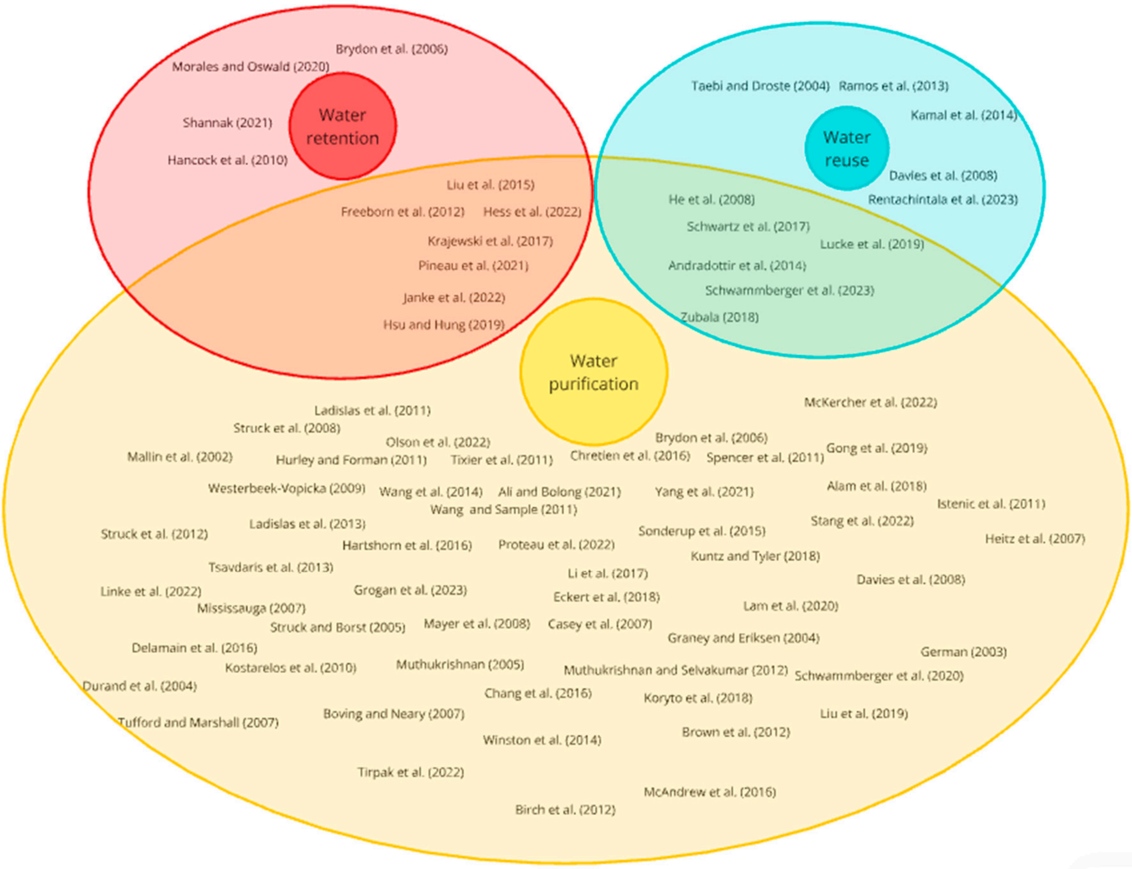

Figure A1. Scheme of reviewed papers according to the described water process. Papers between two circles belong to the two categories which these represent.

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