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Article

Floods and Adaptation to Climate Change in Tourist Areas: Management Experiences on the Coast of the Province of Alicante (Spain)

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Abstract: One of the principal challenges for cities on the Mediterranean coast is the management of urban runoff after episodes of intense rainfall. This problem is aggravated by the effects of climate change, with the increase in the frequency and intensity of extreme weather phenomena in this region. In light of this situation, the local governments, in collaboration with the concessionaire companies providing supply and sewage services, are committed to adopting measures aimed at a more efficient management of non-conventional water resources. Examples of good practice for reducing urban flood risk and adapting to climate change are those actions developed in the tourist municipalities of Alicante, Torrevieja, and Benidorm, where measures have been implemented or have been planned and integrated with green spaces, with a commitment to sustainability, such as sustainable urban drainage systems (SUDS) or Nature-Based Solutions (NBSs). This study analyses these case studies, based on a detailed review of the technical projects that contemplate each of the actions. Furthermore, several field trips were made with technical personnel who are familiar with the measures adopted. The results show that the implementation of these systems contributes to advancing the reduction of urban flood risk and the adaptation to climate change, creating more resilient and safer urban spaces for the citizens residing in them.

Keywords: resilience; nature-based solutions; sustainable urban drainage systems; water reuse; south-east Spain

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1. Introduction

The global warming of 1.1 °C observed with respect to the average of the second half of the nineteenth century in the Mediterranean Basin has already caused an increase in the frequency and intensity of weather phenomena [1], such as rainfall extremes. Furthermore, it is predicted that with a warming of 1.5 °C, torrential rains and their associated floods will be more intense [2], increasing the problems of flooding in urban nuclei. The trends and forecasts of the IPCC (Intergovernmental Panel on Climate Change) [1,3] determine that the Mediterranean will be one of the regions most affected by climate change.

Therefore, the city has become a space of risk, due to the concentration of the population and activities under conditions of increasing climate hazard. In 2020, more than half of the world's population (56%) lived in cities. In Europe, 75%, and in Spain, 81%, of the total population resided in urban areas [4]. These data show the accelerated process of territorial transformation which cities have experienced since the second half of the twentieth century [5]. In the Spanish Mediterranean, this process has taken place with great intensity in the coastal municipalities due to the socio-economic development derived from the boom in tourism activity and the real estate sector [6]. The abandonment of traditional agricultural practices and techniques for exploiting flood waters from the mid-twentieth century have given rise to an environmental and territorial problem which has radicalized its effects over time, and the consequences are becoming more and more severe. The terracing of hillsides, the bottom of gorges and watercourses [7], the development of the so-called "turbid water irrigation" or "boquera irrigation" [8], and the construction of cisterns, tanks, and wells [9], have enabled the waters from the scarce rainfall to be fully exploited in the past. These practices were essential, not only in order to make use of such a scarce natural resource, but also for reducing runoff and for abating the flooding experienced in the gorges and watercourses [10]. They thereby reduced the harm that the torrential waters could have caused, particularly in the lower sections of these arteries, where the population nuclei were largely located.

The urban growth from the 1980s has had a major impact on the drainage of rainwater, due to the design of the sewage networks being insufficient to drain large volumes of urban runoff. The increase in the sealing of the land has led to an increase in flood risk, both due to the occupation of areas prone to flooding and the reduction in natural or permeable urban areas. This problem has been aggravated by the new climate reality, in which the management of runoff in built-up areas has become a principal line of action to mitigate the flooding problems in cities and to increase their resilience to floods.

Traditionally, the management of runoff in urban environments has been conducted with conventional structures (e.g., sewage networks), which Magdaleno et al. [11] refer to as grey infrastructure. Foster et al. [12] place special emphasis on pipes and concrete or metal storage in the management of water in urban environments. However, in recent years, this approach has been changing, with a commitment to a more sustainable management of rainwater, with the implementation of Nature-Based Solutions (NBSs) and Sustainable Urban Drainage Systems (SUDS), which, through natural processes, imitate the natural water cycle and contribute to reducing the levels of surface runoff, improving the quality of water [13,14].

The flood risk management policies have shifted towards natural and ecosystem approaches, seeking to coexist with the phenomena instead of controlling the processes. The objective is to restore to the river ecosystems and marshlands part of the territory occupied by urbanized areas and infrastructures [15]. From this point of view, the aim is not only to mitigate the natural risks but also to use the ecosystem services as part of a wider strategy of ecosystem-based adaptation (EbA), through the comprehensive and sustainable management of the territory in response to climate change [16].

In 2013, the European Commission adopted the EU (European Union) Strategy on Adaptation to Climate Change, indicating that the adaptation measures to respond to the effects of climate change should be implemented on a local, regional, and national level [17]. The objective of this European strategy is to promote adaptation based on ecological infrastructure and ecosystems. To do this, it promotes the so-called Green Infrastructure (hereafter, GI), as nature can provide economic and long-lasting solutions. The European Commission defines GI as:

> "*a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings*" [18] (p. 3).

GI is the roadmap for the sustainable development of Europe, based on the principles of protection and enhancement of nature, integrated in the special and territorial development plan [18]. As indicated in the technical report of the European Environment

Agency, GI is a strategically planned network of natural and semi-natural areas, managed to offer a wide range of ecosystem services, such as the case of mitigation and adaptation to the climate. This network of green (land) and blue (water) spaces can improve environmental conditions, and therefore the health and quality of life of the citizens. To do this, it proposes three key principles of GI: connectivity, multifunctionality, and spatial planning, which are applied on all scales, from urban to rural landscapes. [19]. Within this context, the NBSs for adapting to climate change and reducing disaster risk are actions that work with nature and improve it to restore and protect the ecosystems and to help society to adapt to the impacts of climate change and slow down the increase in temperature, as well as providing many additional benefits (environmental, social and economic) [20].

Among the transforming policies of the European Union is the UN 2030 Agenda for Sustainable Development through the application of Sustainable Development Goals (SDGs). It is vitally important to establish a new horizon in urban flood management, fulfilling *Objective 6 Clean Water and Sanitation*, *Objective 11 Make cities inclusive, safe, resilient and sustainable* and *Objective 13 Climate action* [21] (p. 14). In turn, the Sendai Framework for Disaster Risk Reduction 2015–2030 is focused on the importance of reducing the existing risk and reinforcing resilience [22]. The Spanish Urban Agenda (SUA) is part of the fulfilment of the international commitments adopted in compliance with the 2030 Agenda, the New Urban Agenda of the UN (United Nations), and the Urban Agenda for the European Union, which are focused on the importance of implementing policies and comprehensive plans in cities to mitigate and adapt to the effects of climate change, together with an increase in resilience to disasters [23]. In this respect, the European Green Pact, which integrates the application of the 2030 Agenda and the Biodiversity Strategy of the EU, contemplates new adaptation actions led by Nature-Based Solutions (NBSs) and the Sustainable Urban Drainage System (SUDS). The NBSs are the principal sustainable solutions that imitate the functioning of the natural cycle [24]. This concept is based on the ecosystem approach, where the natural ecosystems possess a diversity of services that provide for human well-being [21,25]. The SUDS favors the management of urban rainwater and the fulfilment of the European guidelines referring to Directive 2000/60EC [26].

The study of the implementation of the NBSs and SUDS has aroused great interest on a global scale, as reflected in the scientific literature, which includes an abundance of case studies that combine the mitigation of floods and the adaptation to climate change with sustainability.

Over the last decade, different international institutions have committed to implementing NBSs to improve the resilience of cities, not only from a territorial point of view, but also from a social and economic perspective, connecting blue infrastructure with green infrastructure as a multi-scale management tool, even from a legal point of view [27]. As examples of this change in paradigm, we can refer to different initiatives on an international level, including the Room for the River program to control the sea level in the Netherlands, the Sponge City Program for managing the flooding of the River Vihn in Vietnam, or the Green City, Clean Waters program in Philadelphia (Pennsylvania, United States) [28]. It is also worth highlighting the *Rotterdam Climate Proof* program, which refers to the strategies developed in urban infrastructure, such as the "water squares," for the storage of rainwater or water storage facilities in car parks, such as Museumpark or Kruisplein [29] (City of Rotterdam, 2013), and the Cloudburst Management Plan in Copenhagen (Denmark), which includes adaptations to improve flood management [30]. In Egypt, eco-hydrological alternatives have been assessed in the optimum way. These include the construction of wetlands and dams for managing flash floods and improving the quality of rainwater [31].

In Spain, strategies for adapting to climate change are gaining impetus, increasing the resilience to the problem of the sealing of the land with the increase in urban area. The National Plan for Adaptation to Climate Change has boosted the increase in green infrastructure as an adaptation measure to improve the management of urban rainwater and the "heat island" effect.

Over the last two decades, there has been growing interest in the implementation of hydro-efficient and sustainable solutions to reduce the risk of hydrological extremes on a local scale and throughout the Spanish territory. The province of Barcelona was a pioneer in this field and currently boasts many examples [32–35], as does the Spanish capital [36–39]. Other provinces that have experienced an improvement in rainwater management are San Sebastián, Santander [36], Vitoria [40], and Seville [41]. In the region of Valencia, over the last decade, the development of these practices has increased and the cases of Benaguasil and Xátiva [14,42], Ribarroja del Túria [43], the center of Valencia [44], Bétera [45], and Benicàssim [46] are well known. In the province of Alicante, the most relevant actions have been implemented in the city of Alicante [5,47,48], although in recent years, measures of this kind have been taken in the district of Bajo Segura, within the action framework of the Vega Baja Renhace Plan [49]. The urban tourism development in the coastal municipalities of the province of Alicante has converted them into spaces particularly sensitive to flood risk, due to the increase in exposure and vulnerability. The objectives of this study are: (a) to analyze the different actions carried out in tourism towns in the province of Alicante which seek to improve the management of rainwater runoff and mitigate flood risk; (b) to highlight the importance of the SUDS and NBSs for restoring the natural water cycle in urban environments; and (c) to give visibility to future measures of adaptation to climate change in the province.

2. Study Area

The area of study is confined to three coastal towns in the province of Alicante: the provincial capital, Benidorm, and Torrevieja (Figure 1). In recent decades, these towns have experienced a considerable extension of their constructed area for urban tourism. In the mid-twentieth century, Alicante was already a consolidated city in which more than 100,000 people resided, while Torrevieja and Benidorm had around 9000 and 2700 inhabitants, respectively. However, the area constructed before 1960 accounts for hardly 9% of the current area, which reveals the strong urban growth experienced from that decade, caused by the absorption of the rural population attracted by the rapid economic development occurring in the town. Meanwhile, Benidorm became in just a few years Spain's principal "sun and beach" tourist destination, mainly attracting foreigners, and from 1960 a large quantity of hotels and residential properties were built in the form of skyscrapers. We can gain an idea of this significant growth from the fact that 56% of today's constructed area was built between 1960 and 1989. In Torrevieja, the boom in "sun and beach" tourism arrived a few years later, mainly after the 1980s, and was initially directed to national tourists with second homes. However, the foreign population subsequently began to increase after 2000 due to residential tourism. In order to appropriately assess the scope of the urban expansion of Torrevieja, it should be indicated that it was the Spanish town with the twentieth largest area constructed between 1980 and 1989, if we take into account the data of the Cadastre as of October 2019. Despite these differences, the three towns share a common feature, which is that, although there had been large urban developments in the past, the decade of the 2000s, amidst the boom of the property bubble [50], was when the greatest expansion of the constructed area took place. Between 26% and 31% of this area was occupied in just 10 years, with Alicante being the most prominent as it was the Spanish city with the seventh largest constructed area.

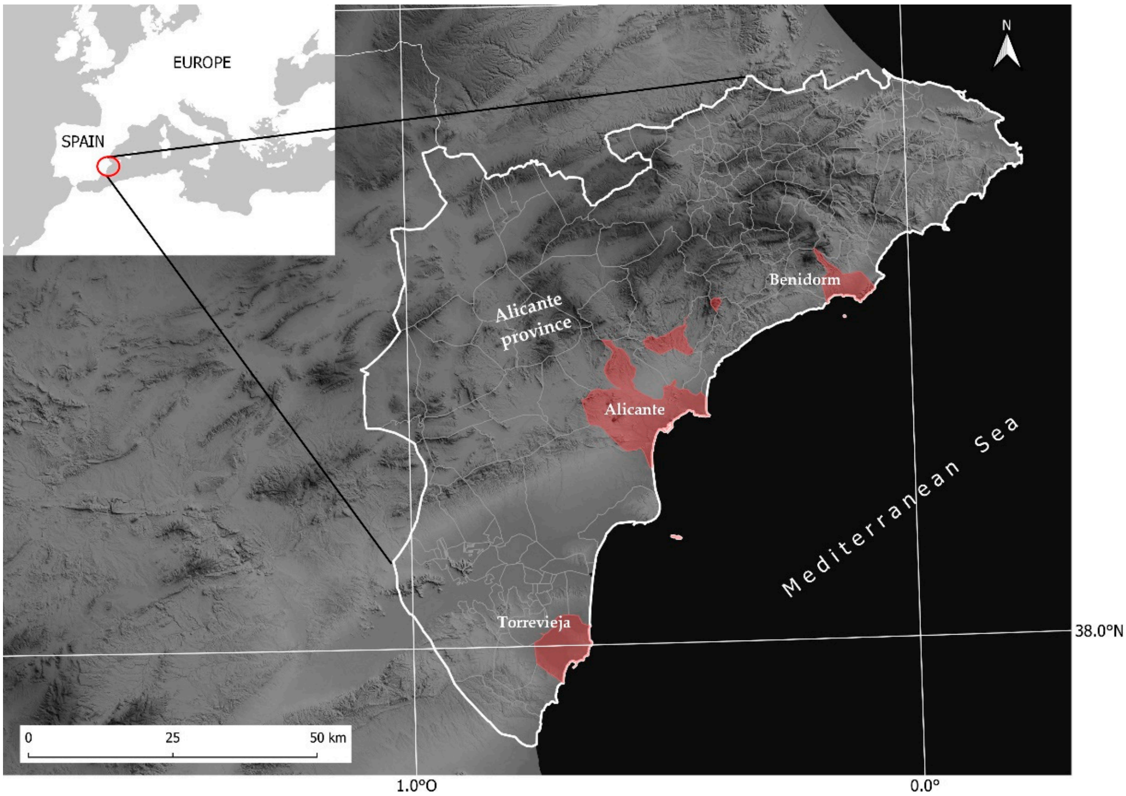


Figure 1. Location of the cases studied. Source: Instituto Cartográfico Valenciano (ICV). Own elaboration.

3. Materials and Methods

The methodology used for conducting this study comprised two phases: first, a bibliographic search related to the topic in order to establish the theoretical bases of the research; second, several field visits to the municipalities selected in order to examine the measures adopted. Different interviews were conducted in December 2021 and July and November of 2022 with the technicians of the local governments (Torrevieja, Benidorm, and Alicante, respectively) and the concessionaire companies of the supply and sewage services, Empresa Mixta Aguas del Arco Mediterráneo S.A. (AGAMED) and Aguas Municipalizadas de Alicante Empresa Mixta (AMAEM). In this way, qualitative information was compiled regarding the measures implemented for managing the runoff until the present day (Table 1), their advantages and drawbacks, and the projects and ideas for the future in terms of the management of this resource in these municipalities.

Table 1. Adaptation measures implemented in the case studies

Measure	Location	Construction Date	Management
Jose Manuel Díez Worker's Anticontamination Tank	Alicante	March 2011	AMAEM
Flooded park "La Marjal"	Alicante	March 2015	
Lamination raft	Torrevieja	1st phase (October 2022)	AGAMED
Renaturalization and connectivity of ravines	Benidorm	-	HIDRAQUA
Flooded park "L'Estany de la Foia"	Benidorm	-	

Source: Own elaboration.

4. Results

4.1. Alicante

In the municipality of Alicante, the local government, in collaboration with the company AMAEM, responsible for the integral water cycle of the city, have developed actions for reducing the flood risk and adapting to climate change which have been acknowledged on an international level.

Like many coastal cities of the Mediterranean, Alicante has suffered from episodes of torrential rains throughout its history that have caused serious flooding in its urban environment. Olcina et al. [5] (pp. 49–55) analyzed in depth the urban evolution of the city of Alicante and how this fact conditioned the development of historical actions in urban drainage from 1791 to 1997. The flood of 30 September 1997 constituted a turning point in terms of the flooding problem of the city. This was when the Comprehensive Flood Plan of Alicante (Plan Antiriadas de Alicante) was implemented. At this moment, there was a change in paradigm in the city's water management, leaving behind the hygienist measures consisting of the construction of collectors that drained the wastewater (sewage system), and adopting resilient measures with the construction of an extensive network of high capacity collectors that transport large volumes of urban runoff water (rainwater network).

The Anti-Flood Plan was an important milestone for the city and was developed in two phases: (1) between 1997 and 2001 the urban draining of the city was improved, increasing the capacity of the obsolete collectors; (2) between 2001 and 2005 the ravines on the periphery and adjacent to the city were channeled [5] (p. 57).

The most noteworthy progress in terms of water has been made in the last two decades, with a decisive commitment to sustainability by the local government and AMAEM. As part of the Special Investors Plan 2006–2016, AMAEM has implemented two actions that have given rise to substantial improvements for urban drainage in Alicante: the first is the José Manuel Obrero Díez Anti-Pollution Tank, and the second is the La Marjal Floodable Park (Figure 2). These measures have a dual function: on the one hand, to reduce the risk of flooding by capturing the first flows of episodes of torrential rain, and on the other hand, to reinforce the reuse of this non-conventional water resource of treated runoff water for urban or agricultural use.

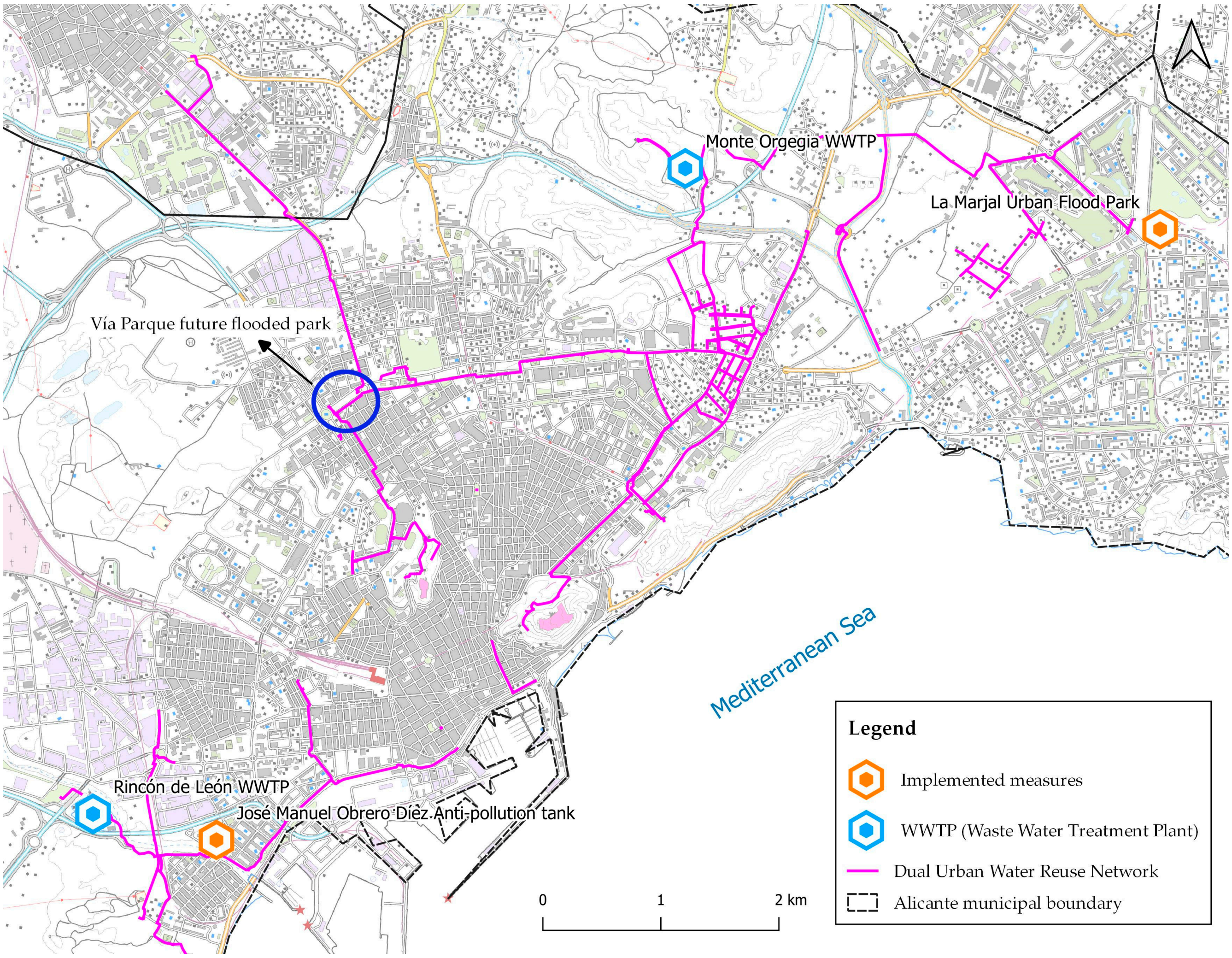


Figure 2. Location of the measures executed in the city of Alicante. Own elaboration.

The construction of the José Manuel Obrero Díez Anti-Pollution Tank (Figure 3) began in June 2009, and it came into operation on 8 March 2011. The tank is located in the neighborhood of San Gabriel, on the left bank of the Ovejas ravine, delimited by Panamá Street, Ecuador Street, Paraguay Street, and Beato Francisco Castelló Aleu Street, under the installations of the Juan Antonio Samaranch sports center. This anti-DSU tank (anti-discharge of unitary system into the environment) has the objective of collecting large volumes of water and avoiding the discharge from the network of unitary collectors of the urban area of the city (approximately 60% of the total network) into the Ovejas ravine, which is what had happened until its construction.

The rectangular tank has two vessels with lengths of 100 and 200 m, a width of 30 m, and a total capacity of 60,000 m^3 for storing flows of water and thereby contributing to preventing the collapse of the sewage networks and reducing the discharge into the Ovejas ravine, and from there, to the sea. For its operation, there is a remote control system that allows the management, in real time, of the tank's installations. The filling of the tank takes place through gravity or through pumping from the connection with the adjacent unitary collectors. After the rain episode has ended, the stored water is pumped, in a controlled way, to the Rincón de León WWTP where it is treated. In this way, the captured rainwater is reclaimed and made suitable for its reuse in the irrigation of parks and gardens, street cleaning, and agriculture, or is discharged directly into the sea. In the case of a complete filling of the tank, a spillway enables the discharge into the Ovejas ravine.

Figure 3. Filling process of the José Manuel Obrero Díez anti-DSU tank. (a) Tank filling through two 1.8 m diameter pipes; (b) Filling the tank; (c) Full tank. Source: AMEM. Own elaboration.

Since its implementation in 2011, the tank has come into operation on different occasions, principally in the autumn and spring months, and to a lesser extent, the winter. To date, 2021 has been the year with the greatest volume of water accumulated; 649,287 m^3. Of this, 19.16% corresponds to the month of March (Table 2). In this year, during the autumn season, the tank stored 220,258 m^3, representing 33.92% of the total volume stored.

Table 2. Total volume stored in the anti-DSU tank and the month with the greatest volume stored.

Year	Total Volume Stored (m^3)	Month with the Highest Storage Volume	Volume (m^3)	P (mm/Month)
2011 (from October)	106,994	-	-	
2012	454,383	November *	454,383	108.6
2013	401,961	April *	148,060	94.2
2014	224,162	November	76,500	58.4
2015	306,750	September	98,496	84.2
2016	430,552.80	December	170,432	114.6
2017	393,192	January	95,681	81
2018	534,457	October	142,037	42.2
2019	585,534	April	135,580	125
2020	392,733	March	109,810	71.8
2021	649,287	March	124,371	48.8
2022 (to July)	510,415	March	189,365	126.8
TOTAL	3,802,920.80			

Source: AMAEM, * [48] (p.13) and AEMET. Own elaboration.

In the year 2012, the construction of the La Marjal floodable park was approved. It began in April 2013 and finished in March 2015. The park is located in the urbanized area of the Playa de San Juan, specifically between Las Naciones and Oviedo Avenues. This area is characterized by being a depressed area, a former marshland which has been transformed by the urban dynamics of residential tourism from the mid-twentieth century. The alteration of the natural dynamics of this space and the undue occupation of floodable areas has generated problems of flooding in the current urbanized areas. Despite the works executed between 1998 and 2000 as part of the Anti-Flood Plan, which consisted of the channeling of the Orgegia and Juncaret ravines and the large collectors of the Oviedo, Países Escandinavos, and Holanda Avenues, they were insufficient and the flood problems continued in certain areas such as the lower part of Pintor Pérez Gil Avenue where the waters reached a high level on the road and caused flooding in the underground car parks of the residential estates "Hoyo 1" and "Palo Alto". Therefore, the "La Marjal" floodable urban park has a double function. On the one hand, its hydraulic function resolves the flooding problems suffered by these urban areas and, on the other hand, it has a distinct social (recreational space) and environmental (green area, promoting biodiversity) character. The uniqueness of this action resides in the conception of a public park with a temporary retention tank, ruling out other alternatives such as the opening of an open-sky channel to discharge water on the beach, or the construction of underground concrete tanks. The work is made up of three different parts: first, the reinforcement and construction of new rainwater collectors in the lower part of the floodable area (Avda. Pérez Gil); second, the piping of the captured water to the park; and, third, the park itself, as a solution for storing the surplus flows of the rain system, and as a public park when it is not in storage. The La Marjal floodable park has a capacity of 45,000 m^3, corresponding to a modelled rainfall with a maximum intensity of 120.2 mm/h and 2 h of duration. Its terraced design enables the principal vessel to be filled slowly (Figure 4). The operation is based on the natural system of the marshlands.

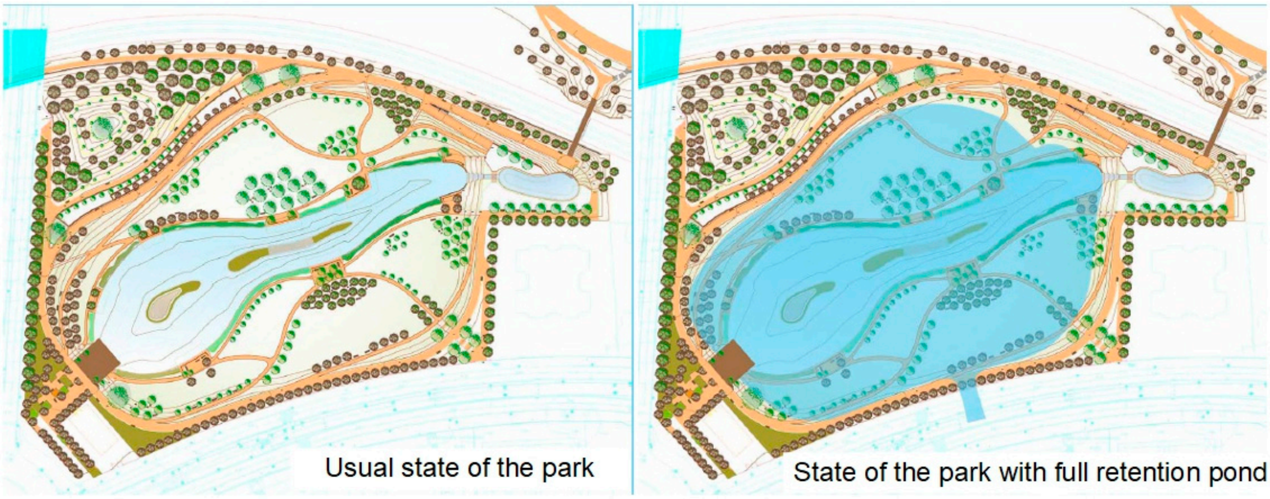


Figure 4. State of the parks before and after an episode of intense rainfall. Source: Adapted from [51].

In the case of a highly intense episode of rain, the flow of water will begin circulating through the existing rainfall network, as it did prior to the construction of the park without the new system coming into operation. As the flow increases, the collector system will fill up until its functional capacity is surpassed. This is when the water will begin to reach the park, filling it after overflowing the side channel, which is designed for this purpose. If the park's capacity is exceeded, there will be a discharge onto Avenida Oviedo by way of a surface channel (Figure 5). If the quality of the water is adequate, it can be discharged directly into the sea through an outlet collector which connects the emptying chamber to the collector in Avenida Oviedo.

Figure 5. Diagram of how the park operates. Source: AMAEM.

The natural environment created in the park mimics a wetlands ecosystem. The pond is surrounded by a fringe of vegetation of aquatic and marsh species, favoring the nesting of birds in the pond and shaping a natural marsh landscape (Figure 6). The floodable area of the park has river tree species, and on the higher part a Mediterranean landscape has been recreated with autochthonous plant species. Furthermore, the existence of explanatory panels makes this space an educational resource for schools and for environmental education [52].

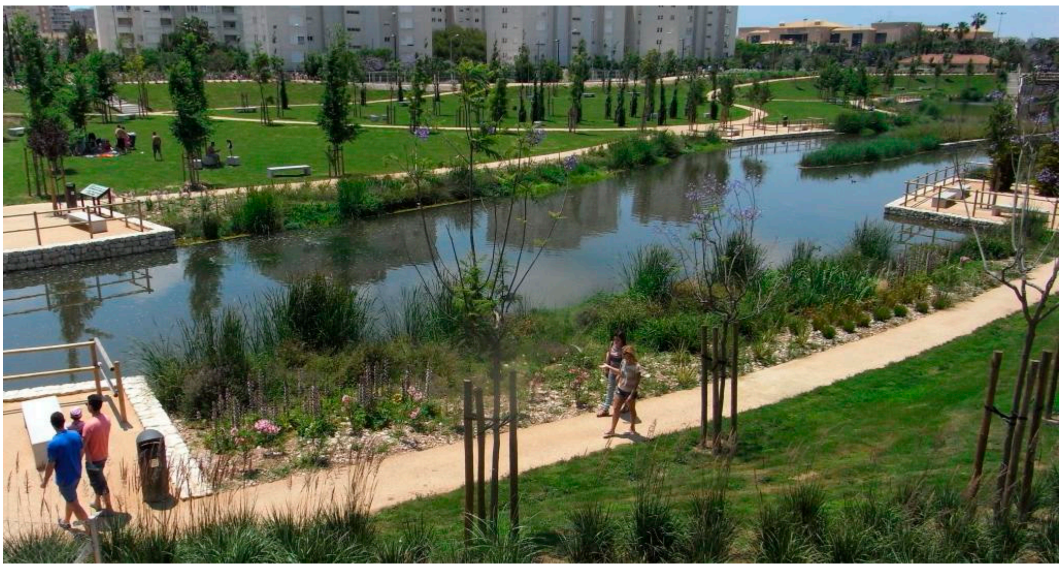


Figure 6. Natural environment of the La Marjal floodable park. Source: [51].

Since it was opened in 2015, the park has come into operation in different intense rain episodes, preventing the flooding of the nearby urban areas. To date, the total storage volume in the park has been 54,300 m^3 (Table 3), with the year 2019 being that of the greatest volume of water, accumulating 24,000 m^3, of which 22,000 m^3 was stored during the intense rainfall episode of 21 August (Figure 7).

Table 3. Total volume stored in the La Marjal Floodable Park.

Year	Volume Stored (m^3)	P (mm/year)
2015	3500	241.2
2016	4500	248.6
2017	8100	361
2018	2100	305.2
2019	24,000	502.9
2020	0	221.6
2021	2100	314.4
2022 (to 01/03/2022)	0	-
TOTAL	54,300	

Source: AMAEM and AEMET. Own elaboration.

Figure 7. Filling of the park during the episode of 21 August 2019. Source: AMAEM.

The water stored after an intense rainfall episode is raised by the pumping station annexed to the park to the Monte Orgegia water treatment plant for its subsequent reuse. The management of this water resource has increased the supply of reclaimed water in the city of Alicante, which has been a pioneer in its exploitation through the development of the Double Urban Water Reuse Network (DRUR) in detriment to drinking water. The DRUR enables the reuse of this water resource in the city for urban, recreational, and environmental use. This water infrastructure supplies the city in two ways: firstly, through urban irrigation networks of gardened areas, and secondly, for urban use through links for individuals for the irrigation of green areas, street cleaning, etc. Since the beginning of the twenty-first century, the consumption of reclaimed water in the city of Alicante has been increasing (Figure 8). To date, the greatest consumption of this resource was in the year 2018, with 1,246,626 m^3.

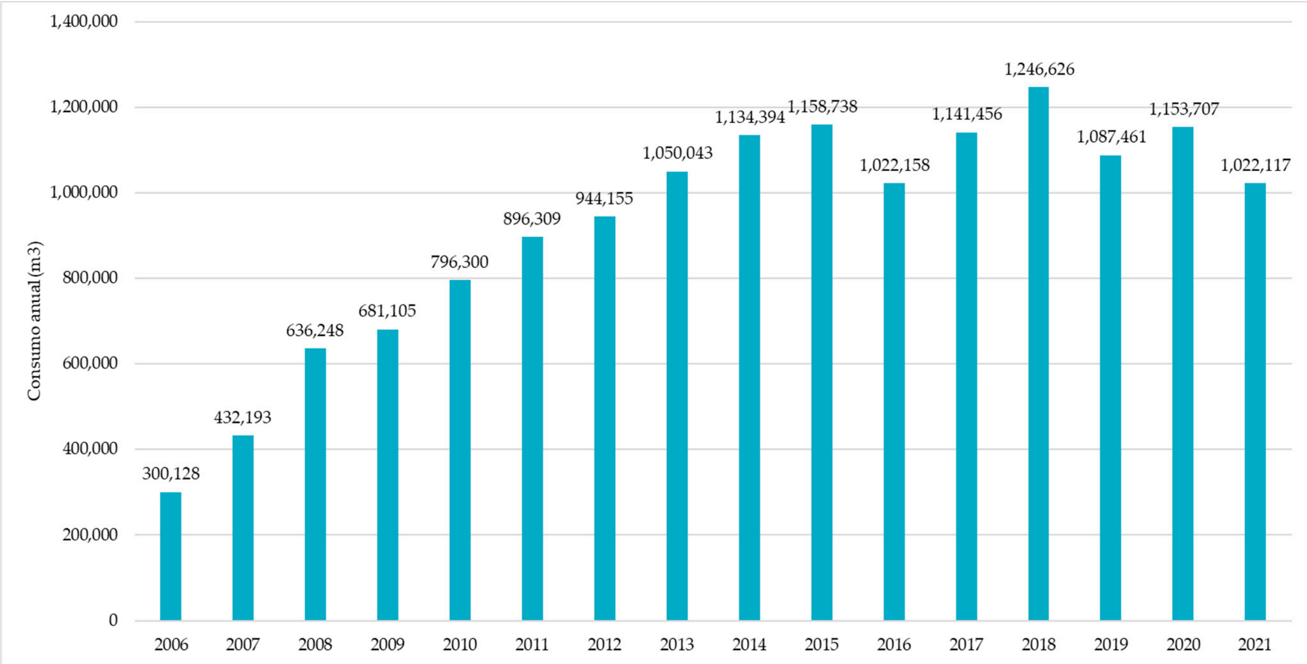


Figure 8. Evolution of reclaimed water in the city of Alicante. Source: AMEM. Own elaboration.

In response to the interest in increasing the resilience of the city to flooding, the City Council of Alicante has proposed a series of actions within the plan "Alicante Agua Circular". The plan is aimed at urban and river renaturalization, with the objective of mitigating the flood risk through the increase in GI and the connectivity of green and blue spaces. To do this, a provisional proposal has been made for the creation of different floodable parks and retention tanks for a total volume of 60,500 m^3, with the objective of preventing the pollution of the Alicante coast and the flooding of certain urban areas. Of these proposals, one that has been evaluated in detail is the creation of the floodable park "Vía Parque" between the Ilustrador Javier Sáez (Avda. Novelda—Jaime I) and Gestor Administrativo (Avda. Universidad—Jaime I) roundabouts (Figure 9). The objective of this action is, on the one hand, to store the rainwater of Avda. Jaime I (which receives the runoff from the streets Virgen de los Lirios and Avda. Universidad) and to increase the water capacity of the San Agustín–Vía Parque collector, and, on the other hand, to reduce the discharges into the Ovejas ravine.

Figure 9. Location of the planned Vía Parque floodable park and recreation. Source: [53]. Own elaboration.

The total surface area of the project is estimated at 16,604 m^2 (Figure 10), of which 978.27 m^2 form the permanent reservoir, which can be extended to 6000 m^2 with a maximum retention capacity of 12,500 m^3. In order to increase the capacity of the park, there will be an underground cistern with a volume of 3500 m^3 that will enable the infiltration of the water and its storage. Furthermore, there will also be a semi-buried tank for marginal waters with a volume of 15,000 m^3, which will store the first flows from the streets Virgen del Puig and Avda. Novelda. When its capacity is exceeded, the flows with a lower pollutant load will be piped to the San Agustín–Vía Parque collector, from where they will be discharged into the Ovejas ravine. After an episode of intense rainfall, the water stored in the tank will be sent to the Rincón de León EDAR [53].

Figure 10. Theoretical diagram of the "Vía Parque" floodable park. Source: [54].

4.2. Torrevieja

The urban nucleus of Torrevieja has grown exponentially since the 1980s. The residential growth has not been matched by comprehensive planning of the urban drainage systems, which is currently causing serious problems in terms of rainwater flooding. Torrevieja suffers from many problems related to floods, with large losses on an economic, social, and environmental level. When there are torrential rains, the main flooding problems occur in the consolidated industrial area, in different urbanized sectors (such as the Torreta-Florida or Doña Inés complexes) and roads (different points on the N-332 and CV-905 roads). In the protected areas of the La Mata and Torrevieja lagoons, the surface runoff waters harm and reduce the production of salt, causing environmental deterioration and a reduction in economic activity. Furthermore, the discharge of large amounts of surface runoff and wastewater has led to the deconfiguration and pollution of the coast.

Currently, the municipality of Torrevieja has no effective drainage infrastructure that enables the drainage of the surface water generated during rainfall episodes. Therefore, most of the runoff water runs down the streets of the municipality until it finds a natural point of discharge in the salt marshes or the coastal areas, frequently generating floods in the streets. Therefore, the town council, in collaboration with the company AGAMED, has proposed solutions to reduce the impact of the floods on the urban nucleus of Torrevieja. AGAMED has conducted an in-depth hydrological study in which eight principal drainage basins have been delimited in the municipal district of Torrevieja (Figure 11) and the principal runoff lines have been identified. Based on these data, a hydrological model has been developed that enables the planning of the infrastructure necessary for the drainage of the surface waters generated in the basins studied.

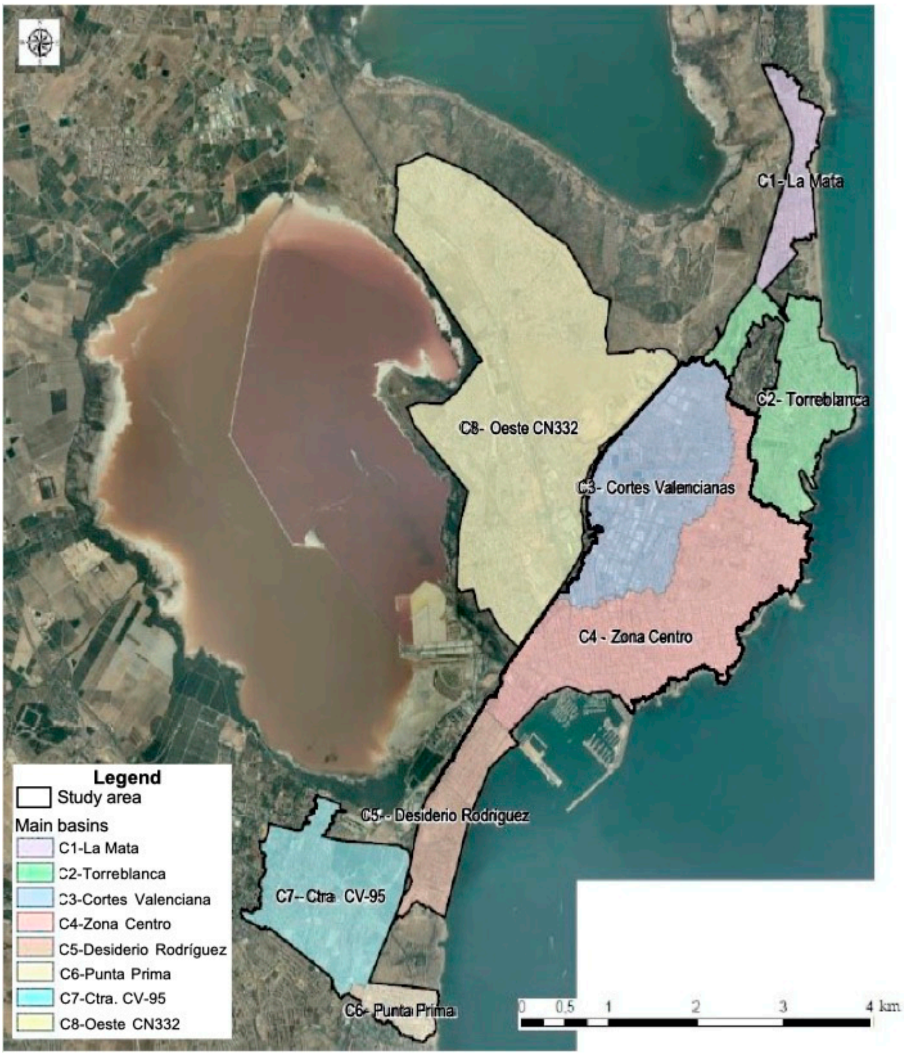


Figure 11. Map of the delimited basins in the municipality of Torrevieja. Source: Municipal water cycle service.

Although some renovation and extension actions have been carried out on the rainwater collectors, and occasional projects have been executed in urban areas and on the principal roads, the problem is still present. Based on recent studies, proposals have been made for the most conflictive locations. Since the torrential rain episode of 11–15 September 2019, which caused accumulations at certain points of 521.6 mm (SAIH of Orihuela) in the district of Vega Baja [55], greater emphasis has been placed on new management strategies focused on the SUDS. The most problematic basins are C3, known as Cortes Valencianas, and C8, known as Oeste CN-332. The latter comprises the area that spans from the summit of Chaparral, a mountain between the lagoons of La Mata and Torrevieja and the N-332 road to the Torrevieja lagoon. The orographic conditions of the basin, with a slope of approximately 40 m from east to west, and the high percentage of impermeable area (around 75%), generate a large amount of runoff that, due to gravity, causes serious problems on the CV-905 road, which crosses the C8 from north to south, and in the Torreta Florida complex, causing the discharge of large volumes of runoff into the afore-mentioned lagoon, which was declared a "sensitive area" by the State Secretariat for Water and Coastal Areas on 25 May 1998 [56]. Therefore, there is a pressing need for a drainage system to improve the management of the rainfall runoff in the area and thereby prevent the discharges into the lagoon which harm the saltwater environment.

In response to this recurring problem during episodes of torrential rain, the execution of a rainwater evacuation system is being contemplated, which consists of a series of ponds interconnected through collectors. At the end of the series, a conduit will convey the stored waters to a discharge point, after passing through a treatment basin which accumulates the most polluted water in order to transfer it to the wastewater treatment plant for its purification. The project is composed of twelve lamination points and has been partially constructed, as its execution is being carried out by prioritizing the most problematic areas (Figure 12). This project has been designed to favor the urban drainage of the city, increasing the area of green and leisure zones for the population. To do this, it will have a "soft" surface, following the philosophy of the floodable parks (Figure 13).

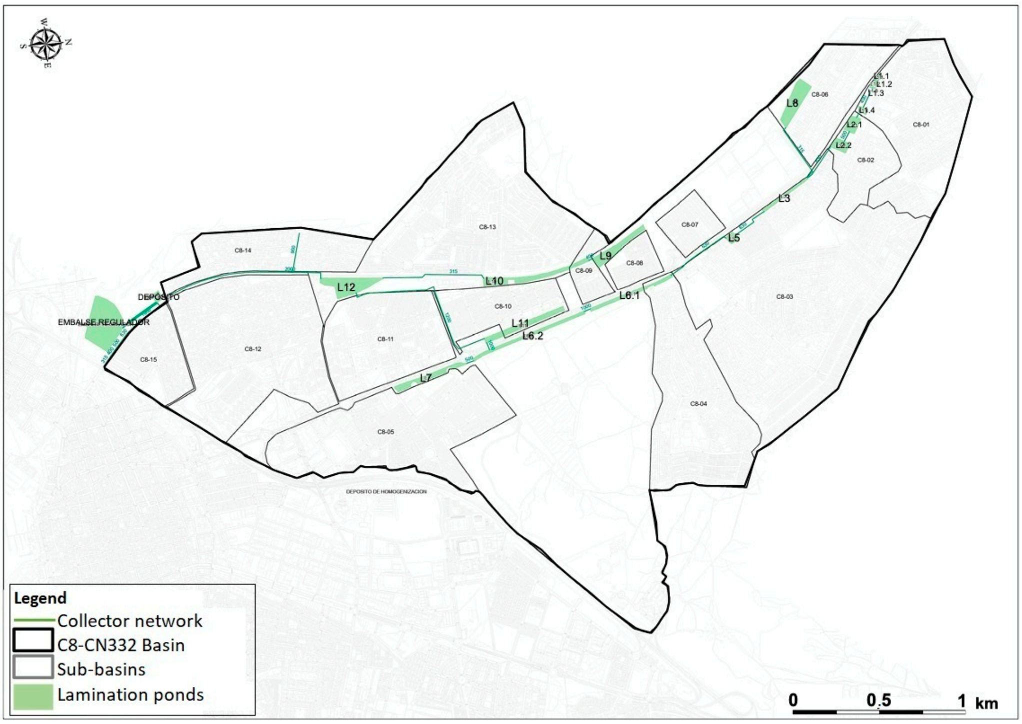
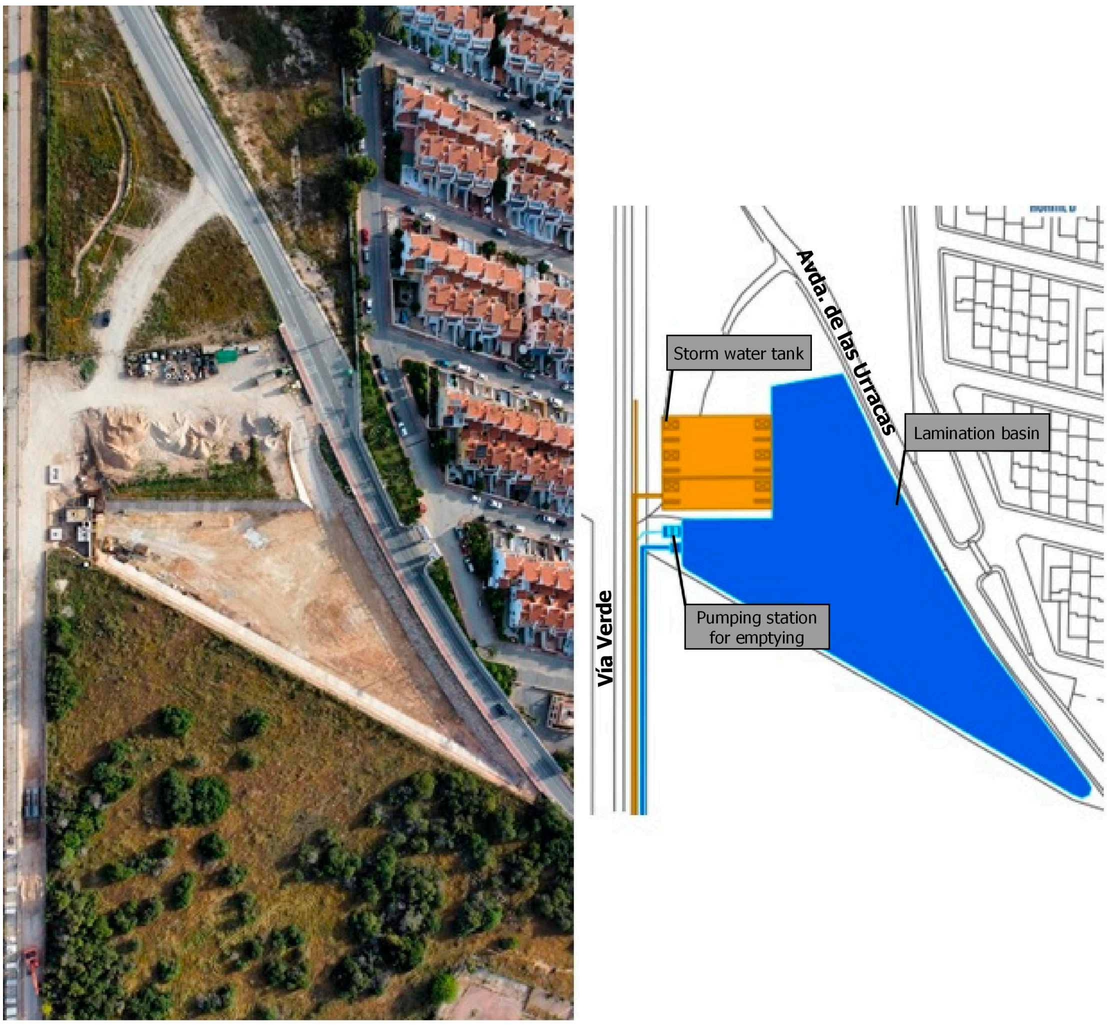


Figure 12. Lamination points planned for basin 8. Source: Municipal water cycle service.

Figure 13. Design of the surface finish of the lamination ponds. Source: Municipal water cycle service.

Currently, the largest pond is in the final phase of construction (L12) and is located in one of the most conflictive areas. This constitutes the end of the drainage system just before the regulating tank and reservoir. This pond, located between the Vía Verde de Torrevieja and the Avenida de las Urracas, has a total capacity of 8000 m³ and an annexed storm water tank of 5000 m³, which has not been executed (Figure 14). The final objective of this infrastructure is to laminate and store the flows from the planned lamination system. This pond is designed to collect rainwater from the whole lamination system, which, through a principal collector, conveys it to a treatment tank (area of 2800 m²). The flows of the basins with a lower topographical height, which cannot be laminated by any of the ponds, are also conveyed directly to this principal collector. This collector begins in lagoon L12 and runs in parallel with the Vía Verde, with a length of 970 meters, until the treatment tank. When the tank has been completely filled, the flow is discharged into a final canal which runs to the regulatory basin (area of 47,000 m²) of the discharge point (5136 m³).

However, the primary function of lamination pond L12 is the storage of the rainwater collected from the pumping and impulsion station at the roundabout of Clarín street, which, through a collector, reaches the lamination pond. When the storm water tank is completed and is active in the system, the water will be conveyed from Clarín street to the storm water tank, where the water will accumulate with a higher polluting load and solids will be decanted. In a situation of intense rains, once the tank has been filled, it will overflow into the lamination pond from where the water will be conveyed to the EDAR for its treatment.



(**a**) (**b**)

Figure 14. (**a**) Lamination pond L12 in construction (24 May 2022). Source: [57] (**b**) Lamination pond L12. Source: Municipal water cycle service.

4.3. Benidorm

Benidorm is the principal tourist center of the Spanish Mediterranean coast. Due to the economic growth and the boom in tourism activity from the second half of the last century, it has experienced a significant process of urban development and territorial transformation over the past sixty years. However, it is true that this development has had a lower impact, as the occupation of the land has not been so intense as in other municipalities of the Alicante coast. Despite this, the changes in the use of the land have given rise to the alteration of the hydrological cycle (filtration processes, infiltration, water retention and its discharge into the sea), and therefore the flood risk has increased, which, according to the special flood plan of the Region of Valencia, Benidorm has a medium risk [58]. Furthermore, the existence of different ravines crossing its urban nucleus highlights the importance of integrating these courses into the green infrastructure of the municipality.

In order to adapt the town to the effects of climate change and increase its resilience to flood risk, the local government has defined a series of strategies based on the reintegration of the green infrastructure in the urban environment, committing to sustainability and the ecological and environmental improvement of its territory.

The ravines with the highest flood and geomorphological risk within the urban nucleus of Benidorm are those of Barceló, Lliret–Derramador, Tapiada–Murtal and, to a lesser degree, that of Xixo (Figure 15). Consequently, there are previous studies, such as the Flood Defence Master Plan for the District of Marina Baja, promoted by the River Basin Organizations of the Júcar (CHJ), which analyze structural solutions, such as the channeling of certain sections of the indicated ravines or improvement of their slopes [59]. However, it was from the year 2019 when the Town Council of Benidorm began to promote sustainable urban actions.

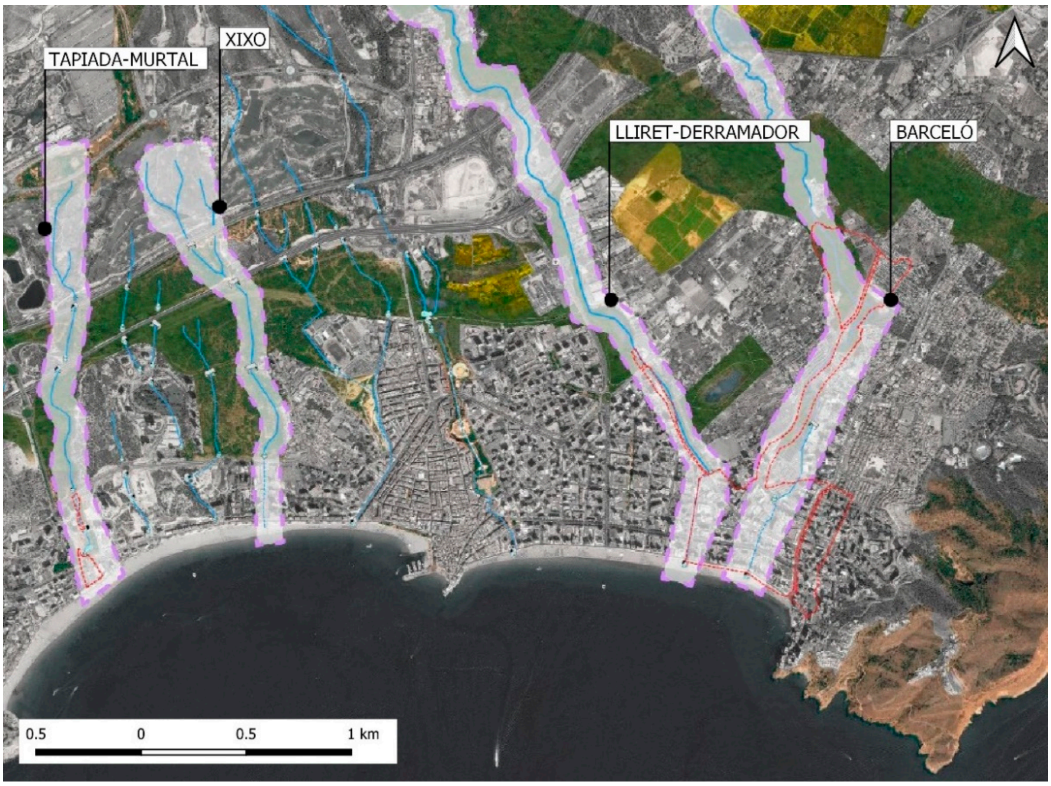


Figure 15. Ravines affected by floodability in the urban nucleus of Benidorm. Source: Town Council of Benidorm.

The ravine of Barceló is the most problematic as it generates floods in the final section of its channel where campsites are located. Therefore, the renaturalised integration of the ravine has been contemplated for two of its sections. The first is between the N-332 and Avda. Comunidad Valenciana (Figure 16a), and the second is between this Avenue and Avda. de l'Almirall Bernat de Sarriá (Figure 16b). This action has the objective of creating a green corridor. Furthermore, the planning of the L'Estany de la Foia floodable park, downstream, in the final section of the ravine (Avda. Ciudad Real-Ctra. Albir) (Figure 16c) has the objective of laminating and storing the flood water from this river artery so as to, first, reduce the flood risk and, second, to create a space for leisure and recreation for the population. This action seeks to create a green corridor throughout the river artery. Furthermore, there are plans to connect the ravines of Lliret–Derramador and Barceló through the green areas existing between the two, without urbanizing them, in order to reinforce the ecosystem improvement and prevent them from overflowing to the east of the urban nucleus (Figure 17).

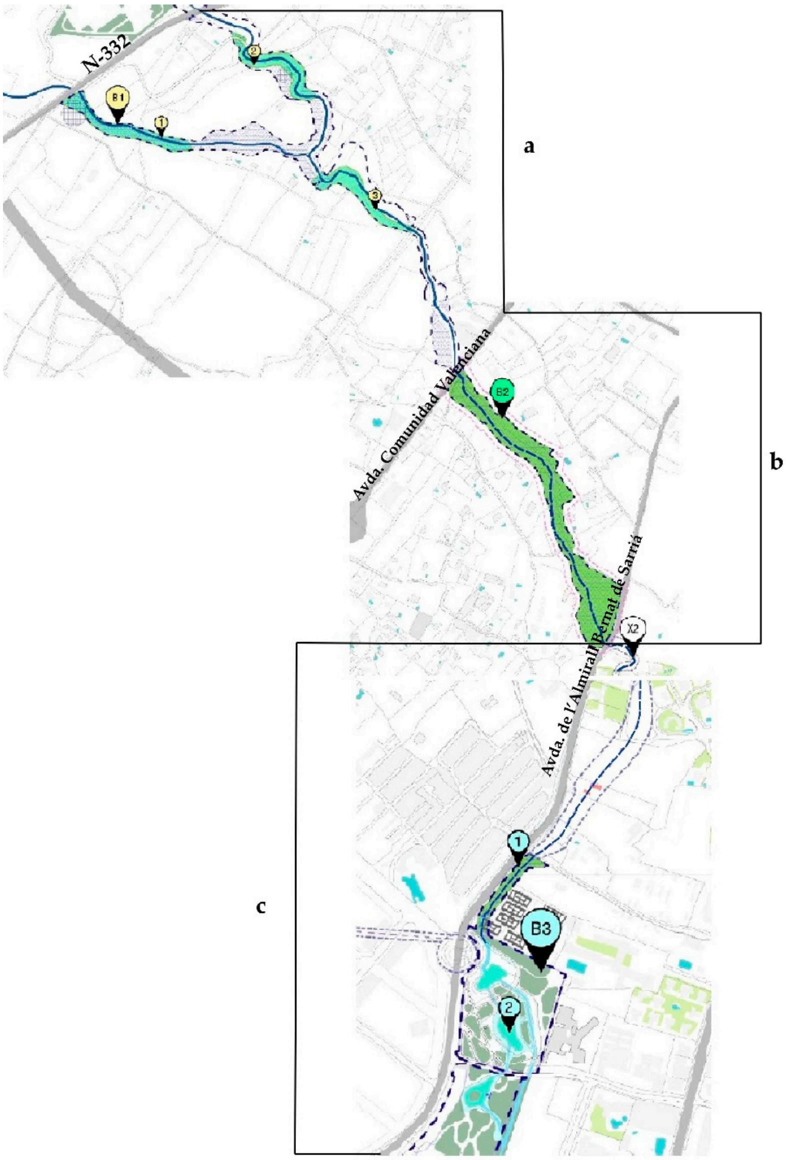


Figure 16. Proposals in the Barceló ravine. (**a**) Renaturalised integration of the northern channel (B1); (**b**) Renaturalised integration of the southern channel (B2); (**c**) L'Estany de la Foia floodable park (B3). Source: Town Council of Benidorm.

Figure 17. Connectivity between the channels of the Lliriet–Derramador and Barceló ravines. Source: Town Council of Benidorm.

These actions seek to reinforce the growth of the GI of the municipality across an area of approximately 25.000 m^2, in order to mitigate the flood risk in the closest urban environment and generate accessible routes with a high environmental value. The recent approval of the Climate Change Adaptation Plan of Benidorm evidences the commitment of the local government to increasing the resilience and sustainability of the municipality [60]. This document contemplates the afore-mentioned measures and the different lines of action to adapt to the effects of climate change. "Line 2. Increase the green, fresh and permeable spaces," involves the creation of a green belt around the urban nucleus which has a double function. On the one hand, it reduces the flood risk, cushioning its impact on the urban environment and, on the other hand, reduces the "heat island" effects. Line 3. "To promote the conservation of the biodiversity" seeks to assess the river vegetation systems, improve the ecosystem services and their ecological function, and to integrate the biodiversity into the municipal district to improve the environmental and landscape quality. "Line 10. Efficient water management" considers the reinforcement of the reuse of the rainwater from the channeled ravines in the urban nucleus.

5. Discussion

In Spain, the SUDS have been considerably reinforced in recent years as they represent an alternative to conventional drainage, although there is still an overall lack of awareness among the population regarding these systems and their function in the environment. With the increase in interest about sustainability in cities, citizens are becoming aware of the importance of the SUDS as an alternative to the management of runoff and have increased their sensitivity towards these systems [33,61].

Some public administrations have worked on the creation of manuals and guidelines for the establishment of design criteria and creation of SUDS [36,62–64]. The design requirements set by Wood-Ballard et al. [62] (p. 45) for SUDS should be for a rainfall return period (T) of 100 years and 6 h duration. In Spain, according to the Guide to Adaptation to Flood Risk: Sustainable Urban Drainage Systems: "The choice and design of these drainage systems depends on the conditioning factors of the environment: the permeability of the terrain, the morphology and climatology of the site, the state of the aquifer and the quality of the water received". [63] (p. 40). In the Valencian Community, the T for rainwater drainage in urban areas is regulated by the regulations of the Territorial Action Plan on Flood Risk Prevention in the Valencian Community [65] (p. 31). For the actions described above, the design criteria are shown in Table 4.

Table 4. Design criteria for the measures analyzed.

Measure	Return Period (T)	Filling Time (min)	Q (m^3/s)	Max. Volume (m^3)
Jose Manuel Díez Worker's Anti-contamination Tank	-	-	27.13	60,000
"La Marjal" Flooded park	T50	120	6.1	45,000
"Vía Parque" Flooded park	T3	-	-	14,246
Lamination pond in Torrevieja	T15	50	3.86	8000
Renaturalization and connectivity of ravines	There are no design criteria as it is a prior approach			
Flooded park "L'Estany de la Foia"				

Source: AMAEM, Torrevieja municipal water cycle service. Own elaboration.

The event-based approach to SUDS design can ensure the proper functioning of the system for those events that do not exceed the proposed magnitude, although the aim of SUDS is not only to manage runoff, but also to favor the reuse and efficient use of water [66] (p. 45).

On an international scale, the city of Rotterdam stands out as a global pioneer in urban water cycle resilience, where water management has been integrated with climate change adaptation. The city has an extensive network of diverse blue–green infrastructure, such as water squares, green roofs and walls, or underground water storage car parks [67] (p. 72) such as the Museumpark car park (which contains 10,000 m^3) or the Kruisplein (2300 m^3) [29]. In Sweden (Malmö), the city of Augustenborg has applied different SUDS typologies such as local ponds, wetlands, or vegetated ditches in recent decades. In addition, they have created multifunctional regional eco-corridors with increased drainage capacity, which are better able to cope with the effects of climate change [68].

Recently in Santiago, Chile, the Victor Jara Flood Park has been opened to the public with an extension of 4.7 km and 41 ha, of which 33 ha are green areas. Its objective is similar to that of the Parque Inundable "La Marjal", namely, to safeguard residential areas which, were affected by the overflowing of the Zajón de la Aguada, and to generate a public space for leisure and recreation [69]. Jiménez Ariza et al. [70] consider green and blue–green corridors in future urban development plans in Bogotá, similar to the approach taken in Benidorm.

On a national level, Barcelona was a pioneer in the implementation of SUDS. In 1998, on a private industrial estate of 30 ha in Sant Bori, green ditches and filter trenches were created with a total storage capacity of 15,000 m^3 [32]. In the urban environment, the Region of Madrid was the pioneer, as in 2003 the Gomeznarro park was conditioned in order to improve natural drainage, reduce erosion, and manage rainwater in situ, through permeable pavements, the installation of 10 percolation tanks in order to favor the collection, storage, and distribution of water, and the renaturalization of eroded areas with vegetation. This action was classified as "Good Practice" by the ONU-Habitat committee [71,72] (p.85).

From this moment, actions taken to improve the drainage systems in the urban parks have been a continuous practice in different parts of Spain. Two recent interventions in urban parks in Madrid integrate the GI in the urban environment. The first was executed in 2016, in the Alfonso XIII Park with an area of 2050 m^2, where the runoff is managed at the origin through the connection of rainwater gardens, so that when the water storage capacity is exceeded a runoff is generated that is directed towards a final retention and infiltration area with a larger volume [73] (p. 11). In 2018, the Atalayuela hill was conditioned through the design of a green area which has characteristics between an urban park and natural landscape. This park, of 9.40 ha, conserves its natural patterns as it recreates the water cycle with an increase in the plant surfaces and the lamination of the runoff with filter drains and rainwater gardens. The use of permeable pavements favors infiltration to existing places [37]. In the north of the peninsula, the actions of Gipuzkoa (2007) and Cantabria (2008) are noteworthy. In San Sebastián (Donostia), in the Kristina Enea Park, filter drains were installed to transport the runoff to infiltration tanks located underground [36]. In Santander, the Las Llamas Park, with a green area of 300,000 m^2, has an artificial marsh and a retention tank [74].

There are different experiences in terms of urban reform or regeneration that incorporate SUDS in order to obtain the most efficient and sustainable management of rainwater. Marañón [40] presents several completed and future projects in Vitoria–Gasteiz, in order to resolve the flooding problems. The actions carried out include the derivation of the rivers to the east of the urban nucleus, which uses an area of the Salburua marshland to undertake lamination and the connectivity between the rivers through an underground collector in order to prevent them from entering the city, with a lamination pond in the Olarizu park. All of the actions have a multifunctional nature and have the objective of the hydraulic adjustment and environmental restoration of the Zadorra river resulting in a large fluvial park integrated into the Green Ring. A similar concept has been implemented in Benidorm, which seeks to renaturalise the four ravines running through the inside of the urban nucleus, reinforcing their connectivity with the creation of green belts that contribute to increasing the GI of the town. At the same time, in the strictly urban part of the municipality, the reform of Avenida Gasteiz is to be carried out, with the creation of a natural channel that will act as a green corridor. Soto-Fernández and Perales-Momparles [34] present the case of the Bon Pastor neighborhood in Barcelona, which was remodeled, integrating the concept of the water cycle into the urban metabolism, modifying the former type of single family home and introducing blocks of flats, leaving spaces for green areas in order to manage runoff. In the areas between the blocks, floodable hollow gardens have been built containing the infiltration wells. In the streets with road traffic, strips of bio-retention material have been placed on the curbs between the street and the pavements in order to intercept the surface runoff, retain the water, and treat water pollutants. Rodríguez-Sinobas et al. [39] analyzed the case study of Valdebebas in Madrid, where SUDS were implemented in the new urban development through the construction of a large area of public green spaces, considering rainwater as a resource for the vegetation. A total of 24 ha of green areas were designed and constructed, incorporating SUDS, increasing the permeable area by up to 65%.

There are many examples of these types of infrastructure in the Mediterranean area. In 2005, the first SUDS were installed in the city of Barcelona in the Torre Baró neighborhood, with permeable strips that divert the water from the roofs of buildings and streets to a cistern (not executed) [35]. In the year 2009, in the Parque Joan Reventós, with a new urban development of 28,000 m^2, drains and filter ditches were created for collecting surface water together with plant-filled ditches that convey the runoff generated in green areas to a retention tank constructed in the flat part of the park [74] (pp. 361–362). A similar case is that of the case study in this article, the "La Marjal" Floodable Park, created in 2015 in the city of Alicante. However, it differs in terms of the objective and the drainage system used from the rest of the urban park actions in Spain, as the purpose of its construction is that of storing and retaining large volumes of water which, at the peak of intense rainfall events, collapse the network. In the absence of rain, it is a leisure space with a pond. The Parque Central de Valencia, the first phase of which was executed in 2018, with a green area of 83,000 m^2, has five accumulation ponds with a volume that varies between 54 m^3 and 323 m^3. Unlike "La Marjal," these storage areas include underground tanks that temporarily retain the runoff, favoring their infiltration through wells connected to the permeable layers for recharging the aquifer [44,65]. Other actions in the province of Alicante studied by Sánchez-Almodóvar et al. [49] highlight the importance of the creation of green areas, such as the El Recorral en Rojales Park for managing water and increasing environmental quality and sustainability. Similarly, the floodable pond of San Fulgencio improves the management of the runoff in the sports facilities where it is located. A similar approach to that analyzed for Torrevieja is used in the cases studied by Casal-Campos et al. [75] and Perales-Momparler et al. [14] in Xátiva and Benaguasil (Valencia), with drainage actions using road ditches, detention–infiltration ponds, and collection tanks.

Despite their importance, these actions also have limitations due to the geographical and climatic characteristics of the Mediterranean region. Each system requires certain characteristics for its correct operation. Among the limitations of the storm tanks are: the need to be integrated in a treatment chain for the elimination of pollutants from the temporarily stored water, the rigorous maintenance , and the high investment costs. The depth of the tanks is a key feature, because tanks with depths less than 4 m lose hydraulic efficiency [76]. Some barriers to the implementation of artificial wetlands or ponds include the need for large areas of surface land for their construction, making them a difficult solution to adopt in densely populated urban areas, and requiring other types of previous systems to prevent the arrival of sediments and requiring controlled maintenance of the water surface. As for detention basins, some limitations include the need for large areas with little slope in the terrain, and periodic elimination of pollutants to avoid their decantation. If the system is used for other purposes such as leisure and recreation, maintenance will be greater and the outlets of the system can become blocked [77].

SUDS are the ideal systems to mitigate stormwater drainage problems on a local scale. The pluviometric characteristics can be a limitation, since in the area under study there are frequent rainfall events of high hourly intensity that usually exceed the design magnitudes and return periods. Given the importance of the pluviometric characteristics of the study area for the design of these systems, it should be noted that different climate studies indicate that the percentage of precipitation that has grown the most in the last two decades on the Spanish Mediterranean coast is precisely that which is included in the threshold between 50 and 100 mm/h, which if they occur for 60–90 min are enough to cause problems in cities [47,78].

SUDS are useful in events not exceeding 100 mm/h, and in semi-arid and Mediterranean climate areas their effectiveness is very high for episodes between 35 and 50 mm/h (Table 5). However, they lose effectiveness thereafter because the amount that can accumulate exceed the design flow [79]. In the cases of the Jose Manuel Díez Worker's Anticontamination Tank and "La Marjal" Flooded park, their efficiency has been proven during different rainfall events. The first, during the episode of 19–20 October 2016, stored 58,416 m^3, of which 31,434 m^3 accumulated on the 20th, when in just 30 min 21.2 l/m^2 were collected [48] (p.14). Elsewhere, its effectiveness was tested in some episodes such as 13 March 2017 (150 mm in two and a half hours) and 21 August 2019 (150 mm in two and a half hours).

These actions are considered to mitigate local micro-scale flooding problems and not for large flooding episodes such as the one that occurred in the Lower Segura in September 2019. Therefore, it is important to point out that, although they are not the definitive solution, they are necessary works for the mitigation of flood risk and adaptation to the effects on rainfall of the global warming process.

Table 5. Effectiveness of the measures analyzed.

Measure	Effectiveness of Infrastructure	Episode Justifies its Construction	Episode Justifies its Effectiveness
Jose Manuel Díez Worker's Anticontamination Tank	Very high	30 September 1997	21 August 2019
"La Marjal" Flooded park	Very high	30 September 1997	19–20 October 2016 *
Lamination pond in Torrevieja	No data	12–14 September 2019	No data
Renaturalization and connectivity of ravines	Under construction	5 October 2014	No data
Flooded park "L'Estany de la Foia"	In project	5 October 2014	No data

Source: * [48] Own elaboration.

As indicated by Perales-Momparler et al. [42], it is necessary to focus research on sustainable urban transformation on a city scale, as governance and planning are key points for their change [80]. Therefore, studies are required that value the need to implement SUDS in strategic areas to maximize the synergistic benefits [81].

6. Conclusions

Risk reduction and the adaptation to climate change are two actions necessary in urban nuclei and will continue to be essential in the coming decades. They constitute two issues that are closely related to the alterations that the warming of the earth's surface is causing in the general atmospheric circulation. In fact, the increase in the frequency of extreme weather events will be a constant feature over the next few decades, according to climate change models [1]. The Mediterranean basin is one of the regions that is most clearly manifesting evidence of the global warming process in the climate elements and atmospheric instability processes, due to the effect caused by the increase in the temperature of the sea in this geographical space. Over the last two decades, intense rainfall episodes have been recorded more frequently in this Spanish coastal region. The province of Alicante has suffered from several events of this type which have caused serious economic damage and even the loss of human lives, particularly in the coastal population nuclei with a clear tourism vocation.

Consequently, actions have been carried out to reduce the risk of torrential rains in different tourism towns in the province of Alicante. This analysis reviews the case studies of specific actions in the municipalities of Alicante, Torrevieja and Benidorm. In the province of Alicante, the adaptation measures to flood risk have been pioneering, such as the "La Marjal" Floodable Park and the José Manuel Obrero Díezo Anti-polluting Tank, implemented in the city of Alicante. The lamination pond in the municipality of Torrevieja has recently come into operation. In Benidorm, the measures presented are future proposals to which the local government is strongly committed, as they form part of the recently approved Climate Adaptation Plan. In the case studies of Alicante and Torrevieja, future proposals are also presented which reveal the relevance of the management of runoff in the urban environment, where the increase in the GI is an integral measure for reducing rainwater runoff with the increase in permeable areas and the adaptation to climate change with the reduction of the "heat island" effect.

The cases studies are the most representative as they are densely populated nuclei and have a high degree of vulnerability and exposure to the flood hazard. The construction of SUDS and NBSs for reducing risk and adapting to climate change has become a highly important measure to improve the tourism image of these population nuclei as they seek to protect the population against these extreme events. This aspect is one of the essential requirements of tourists in a tourist destination. However, such actions may be limited in the event of extraordinary precipitation events where the intensity is very high and the system is overwhelmed.

In this respect, the efficiency of the actions of Alicante and Torrevieja in different intense rainfall episodes has been proven: in Alicante on 13 March 2017 and on 21 August 2019, and in Torrevieja on 11 November 2022 (unmonitored). The lack of data prevents us from assessing in detail the efficiency of all the actions, as they have only recently been launched and others have not yet been implemented. Both actions were able to mitigate the flooding problems in the areas where the measures have been implemented. Furthermore, the "La Marjal" floodable park has received different prizes and recognition: in 2017 it was awarded the "Albert Serratosa" prize from the Foundation of the Spanish Professional Association of Civil Engineers; in 2018 the "Sustainable City" prize from Ecomed-Forum Ambiental was awarded to the city of Alicante, in the integral water cycle category for sustainable management; and in 2019 it was acclaimed by Forética in the Adaptation to Climate Change Toolkit and by "Community for Climate", being considered an efficient model of action for the climate fight.

Over the next few years, the development of these types of action in other urban nuclei of the Spanish Mediterranean coast will be decisive and the three cases analyzed can serve as examples of good practice to apply in other coastal tourist destinations. These actions are in keeping with the determinations of the Spanish Law 7/2021 on climate change and the necessary compliance with SDGs 6, 11, and 13. The change of paradigm in the urban drainage strategy can give rise to difficulties in densely built cities where the urban growth model has been a predator of the territory and the increase in green areas and renaturalization constitute a challenge. In this respect, the situation of Benidorm is optimum for the development of adaptation strategies that have GI as the principal axis.

The implementation of sustainable measures for managing runoff water is gaining importance in the integral water cycle, as they represent an adaptation to the effects of floods and drought, contributing to the creation of more resilient cities. To do this, and due to the limited existence of scientific evidence on the function of these systems in southeast Spain, the dissemination of these experiences is fundamental for enhancing the knowledge and environmental education of society, as these solutions require social responsibility for their maintenance and effectiveness in order to respond to the social challenges of the twenty-first century [24].

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