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Urban Drainage in Barcelona: From Hazard to Resource?

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ABSTRACT: Our objective in this paper is to trace the historical trajectory of urban drainage in Barcelona from the 19th century to the present highlighting the main changes in approach, from the 'everything down the drain' philosophy of the 19th century to the sustainable urban drainage systems of the early 21st century. In this trajectory we identify four main historical periods. The first period corresponds to the 'Garcia Faria Plan' of the late 19th century which initiated the construction of modern drainage in Barcelona. The second period, lasting for much of the 20th century, showed the expansion of the centralised sewer system that, however, could not solve the chronic problems of flooding and pollution created by fast urbanisation. The third period, governed by the Olympic Games of 1992 and the rehabilitation of the beach front, entailed a massive reconfiguration of the sewer system now connected to wastewater treatment plants and enhanced with a number of large underground stormwater reservoirs. Finally, since the early 2000s, urban drainage is increasingly adopting decentralised, small-scale solutions to drainage such as Sustainable Urban Drainage Systems (SUDS). While signs of the transition towards a more sustainable approach to urban drainage are already present, the conventional approach remains strong and appears to be evolving also towards more sustainable solutions. Hence, system coexistence rather than substitution appears to be the outcome of the transition in urban drainage in this city.

KEYWORDS: Urban drainage, history, security, sustainability, Barcelona

INTRODUCTION

Secure and sustainable urban drainage systems, that is, systems that carry, either jointly or separately, stormwater and wastewater flows, are a fundamental aspiration of city planning. It is unfortunately still far from being achieved in many urban areas of the world. Secure systems imply that the hazards of flooding and disease are eradicated, at least regarding their impacts in terms of human lives, while sustainable systems would challenge the philosophy of "everything down the sewer and away from the city" that has traditionally dominated drainage planning (Goubert, 1989). Instead, these systems aim at reducing pollutants and reusing water within or close to the city (Chocat et al., 2001; Brown et al., 2009). Thus, and in contrast to the more conventional, centralised sewers, distributed new technologies such as Sustainable Urban Drainage Systems (SUDS) encourage hydrological abstraction processes (evapotranspiration and infiltration especially) that subtract water from runoff and reduce the problems of flooding and pollution downstream (Elliott and Trowsdale, 2007; Cettner et al., 2013; Carlson et al., 2015). At the same time, beneficial effects for local hydrological cycles (e.g. groundwater recharge) are enhanced. The change in approach is not merely technical but may have also profound implications in terms of local water governance, with the emergence of new actors in urban water management. It may also have implications at the more general level of urban and regional planning

(Van de Meene et al., 2011; Porse, 2013). For these reasons, the adoption of new approaches may be significant enough to induce systemic change (Brown et al., 2013). This can be studied using transitions theory and especially the so-called Multilevel Perspective (Geels, 2006; Geels and Schot 2007; Brown et al., 2009; Geels, 2010). In this paper we assess the progress towards secure and sustainable urban drainage systems in Barcelona by tracing the historical trajectory of this city in managing urban drainage flows as outlined by the transition theory. To provide for a more adequate framing of this theory in terms of place and structural factors (Shove and Walker; 2010; Lawhon and Murphy, 2011; Coenen et al., 2012) we also use insights of other disciplines such as Geography (Gandy, 1999); Urban and Environmental History (Melosi, 2000) and Political Ecology (Swyngedouw, 2004; Kaika, 2005).

The Barcelona combined sewer system (mixing rainwater and wastewater) currently serves a population of about 1.7 million and all commercial and industrial activities located in the city, including a growing tourist sector (Chesa, 2016). The history of urban drainage in the city until fairly recently is one of expansion and consolidation of the traditional model of the 19th century consisting in removing stormwater and wastewater as rapidly as possible from the city in order to avoid the hazards of flooding and pollution. As in the evolutionary chart of Brown et al. (2009: 3), large-scale, centralised infrastructure under the command and control of expert knowledge (basically provided by civil and sanitary engineers) became the main instrument to achieve this fundamental objective. Although still grounded in the expansion and technological intensification of the sewer system (especially on the occasion of the Olympic Games of 1992), since the early 1990s conventional drainage began to show symptoms of change first and foremost by tackling the pollution problem near the source with the construction or renovation of advanced wastewater treatment plants. In parallel, the construction of underground reservoirs recognised the limits of system capacity and, while still a typical engineering solution, reduced flooding in the city substantially. The final approach, still very incipient, adhered to the idea that stormwater flows were to be captured and reused when possible and, especially, before reaching the sewer network and becoming too polluted. This approach would correspond to the so – called 'water sensitive city' of Brown et al. (2009) in which previous large and centralised systems cease to be the only solution in drainage policy and may have to face the challenge posed by integrated, distributed and flexible systems also under different governance structures.

Our main research question in the paper is to assess how a more detailed history of urban drainage in Barcelona, as expressed in planning documents on this topic, may confirm the main contours of change according to transitions theory enriched with contributions from Geography, Environmental History and Political Ecology. Here we will follow the aforementioned framework provided by Brown et al. (2009) describing the transition from the 'water supply city' to the 'water sensitive city'. Focusing on Barcelona, our aim is to test broadly the main stages of the transition and to ascertain whether the interpretation of changes can benefit from the insights provided by adding more explicitly the geographical and historical contexts surrounding the transition. Of particular relevance is whether the conventional sewer system is not only able to resist change (the obduracy effect pointed out by Moss, 2016) but also to pursue a certain, different path towards more sustainable drainage management. The paper is organised in five sections. After this introduction we present the theoretical framework. It departs from transition theory and the multilevel perspective in urban water systems to highlight advantages and shortcomings of the latter, to be addressed by approaches from Geography, Environmental History and Political Ecology. This is followed by a brief account on methods and the study area. The fourth section, divided in four periods, builds a narrative on the history of urban drainage in Barcelona since the 19th century as revealed by the most relevant planning documents and projects. Finally, the fifth and final section presents the main findings and lessons to be learnt from the Barcelona case both regarding theory and practice.

THEORETICAL APPROACHES IN THE TRANSITION TOWARDS SUSTAINABILITY OF URBAN WATER SYSTEMS

Voices criticising current urban drainage systems and signalling a new period in the management of water flows in cities are gaining momentum both in the academic and professional worlds (see, for example, Pahl-Wostl, 2007; Cettner et al., 2013; Marlow et al., 2013; Carlson et al., 2015; Hofmann, 2015). Arguments usually deployed to build a case against conventional systems and propose new solutions usually revolve not only around climate change and related impacts, especially increasing flooding episodes (Cousins, 2017; Stakhiv, 2011; Walsh et al., 2012; Zhou, 2014) but also around issues of governance and citizen involvement (van de Meene et al., 2011; Bos and Brown, 2012; Porse, 2013; Brown et al., 2013). In both cases, infrastructures and institutions need to be flexible, adaptable and integrated if resilience to future risks posed by urban water flows is to be managed adequately (Roy et al., 2008; Brown et al., 2009).

Urban water systems have been one of the preferred themes of a relatively new current in environmental theory roughly framed around the issue of transitions towards sustainability (Geels and Schot, 2007; Kemp et al., 2007; Bos and Brown, 2012; Brown et al., 2013). In fact, one of the most well-known scholars working with this approach, Frank Geels, used the historical change in urban water hygiene in the Netherlands to illustrate the importance of behaviour as well as of technology in governing transitions (Geels, 2006). In essence, transition theory posits that sustainable or unsustainable practices obey to the particular coevolution of technological and social factors mutually influencing each other (Geels and Schot, 2007). This mutual influence takes place at a variety of scales or levels deriving in the formulation of a Multi-Level Perspective in which transitions are said to occur at three levels: First, the micro-level or niche is the cradle of new technological developments subject to experimentation or 'learning by doing' by stakeholders who may be unhappy with existing artefacts and want to try new sustainability tools. Next, at the meso-level, we find regimes, which form the constellation of rules of behaviour concerning the use of particular technological or managerial tools as practised by stakeholders in the socio-technical system. Regimes may attempt to accept or resist changes originating at the niche level. Finally, at the macro-level, landscapes concern the contextual factors, from economic conditions to cultural values, environmental problems, etc. surrounding the system (Geels and Kemp, 2007). Changes in these contextual factors may act in favour of new niches and regimes (for instance, the adoption of grey water recycling under a context of water scarcity (Domènech at al.; 2015) or, on the contrary, interrupt pathways towards more sustainable futures. In the case of urban drainage, new socio-technical developments such as Sustainable Urban Drainage Systems (SUDS) would have initiated the transition from niches to regimes following the principles of the Circular Economy (Pearce and Turner, 1990; De Haan et al., 2015). Proponents of transition theory, however, introduce several caveats in this general framework. Thus transitions may be long (up to 50 years) and a multiplicity of different pathways may appear reflecting conditions in the landscape, regime and niche levels (Brown et al., 2013). At any rate, in the case of urban drainage, new technologies such as SUDS would tend to replace (albeit probably slowly) the former sewer systems as the main approach to drainage management providing more sustainable and secure urban drainage networks as, for example, in cities such as Melbourne (De Haan et al., 2015).

Transition theory and the Multi-Level Perspective have not been immune to a number of criticisms. First, transitions are implicitly assumed to be relatively straightforward following a clear evolutionary road. In fact, however, transitions are often the contrary. Hurdles to change abound, so that these processes are never smooth (van den Bergh et al., 2011). Another problem is what Moss (2016) calls the obduracy of old systems and the fact that old systems, say the conventional sewer networks, can accommodate to and coexist with alternative technologies such as SUDS without changing fundamentally their status and position of privilege. Another interesting issue raised also by Moss (2016) concerns the supposed novelty of systems that will in theory replace traditional urban sewers. RWHs and SUDS, for instance are in fact, technologies that have existed for millennia around the globe in both agrarian- and more urban-oriented societies.

Geographers have also contested transitions theory on the grounds of the little attention paid to spatial issues especially at scales smaller than the national state (Coenen and Truffer, 2012; Coenen et al., 2012). Spatial contexts cannot be simply included as part of the myriad of factors included in the macro or landscape level as a more or less general and passive background for niche or regime dynamics. Rather, spatial contexts intervene decisively at all scales and their specificity is what, among other factors, contributes to set the directions and timings of transitions. For example, the transition towards SUDS would be remarkably different, if occurring at all, in a spatial context characterised by extreme rainfall patterns and high urban densities than in a spatial context less dense and with more regular rainfall. While, proponents of transition theory may argue that this is already taken into account in the landscape level, a more explicit and comprehensive consideration of spatial issues would certainly improve the transition framework, not the least for comparative purposes.

Another set of critical views of transition theory questions its relative aloofness from social and political issues as dealt with in political ecological perspectives. Lawhon and Murphy (2011), for instance, argue that sustainability transitions need to engage more with other dimensions of sustainability such as social justice, equity in access to resources and protection of risks or effective participation in decision-making. A more explicit focus on the Global South (largely missing in the transitions literature) would probably help to correct this shortcoming. At a perhaps more fundamental level, unequal power relations, central for political ecological perspectives, and their influence in governing transitions are said to be not recognised enough despite claims on the contrary. The main criticism here is that technological developments do not occur and evolve in isolation from social processes that shape the characteristics and direction of science and technology. In the case of SUDS, for example, their development is currently often linked to large operations of urban rehabilitation of degraded neighbourhoods as part of a more general sustainability package. For authors such as Anguelovski (2016) this entails the paradox of achieving sustainable objectives by promoting SUDS while at the same time using these very same environmental amenities for inducing gentrification processes.

Lastly, the very same concept of transition implies a temporal dimension which should be approached historically. Here again, transition theory would benefit from the insights provided by historical accounts of the relationship between water and urbanisation (Gandy, 1999; Swyngedouw, 2004; Kaika, 2005; Melosi, 2010; Karvonen, 2011). It is often implicitly assumed that drainage systems follow urbanisation (Brown et al., 2009; Zhou, 2014; De Haan et al., 2015). However, water-related infrastructure may also influence the characteristics and direction of urban growth so that the growth of urbanisation and of water supply, drainage and sanitation are mutually reinforcing (Swyngedouw, 2009). Likewise, adopting a more formal historical analysis would allow for a better indication of transitions paths that may be socially unjust or unsustainable (Offen, 2012).

METHODOLOGY AND STUDY AREA

In order to trace the main steps in the history of urban drainage systems in Barcelona and analyse the evolving position of security and sustainability of these systems we have opted for the methodology of documentary analysis. Thus we have reviewed in detail different plans dealing with stormwater and wastewater flows drafted and developed by the city council and related agencies since the late 19th century (see Table 1 for a brief summary of the main plans). Most of these plans address specifically the expansion of the sewer network and its increasing technological sophistication and also reflect an increasing variety in scale (from the city to the metropolitan area) and scope (from drains and sewers to underground reservoirs and to SUDS). By using direct documentary evidence we expect to develop an account of the history of urban drainage in Barcelona as close as possible to the original intentions but also the difficulties encountered by the proponents of the different plans.

We have also used published literature (especially on the older plans) and interviews with a few key actors (for the newer plans). In the following sections we explore this historical trajectory for the case of Barcelona, beginning with the first water sanitation plan in the late nineteenth century and ending with the current plans to foster secure sustainable drainage and sanitation networks. Before this, however, we offer a brief introduction to the physical and human geography and to the history of the city and especially on how these geographical and historical factors have influenced urban drainage.

Barcelona, located in the North-western Mediterranean, shares many features with other cities of the Mediterranean Basin. First, it has historically expanded over a narrow coastal plain backed by mountain ranges of moderate heights but falling quite steeply towards the sea. Runoff from these ranges produces frequent episodes of flash flooding especially after heavy rainfall. Rainfall intensities of 133 mm in 15 minutes and of 54 mm in one hour have shown a return period of only ten years (Ajuntament de Barcelona, 1988). Likewise, the main rivers nearby, Besòs and Llobregat, observe long periods of low flows and sudden floods in which peak flows can rise by several orders of magnitude (Llasat et al., 2014). Stormflows tended to accumulate in the lower parts of the city close to the coastline causing endemic inundation and beach degradation. At the other extreme of the hydrological spectrum, the irregular nature of precipitation in the Mediterranean is responsible for frequent droughts as well. In early 2015 Barcelona broke a record of more than 90 days without any rain and in 2008 a prolonged drought forced the shipment of water to Barcelona by sea tankers (March and Saurí, 2013). On the human side, Barcelona occupies an area of 97 square kilometres (km^2) almost all totally urbanised. Density approaches 18,000 people/km^2, one of the highest in Europe (Ajuntament de Barcelona, 2016). An extremely compact, highly impervious urban layout exacerbated flooding especially, as said before, in the neighbourhoods closer to the sea. Moreover, since stormwater carried heavy pollution loads, water, soil, and landscape quality deteriorated accordingly producing the environmental degradation of the city and of its beaches (Saurí et al., 2014). The management of these unwanted flows marks the history of urban drainage in Barcelona during the last century as we will attempt to show next.

STEPS IN THE HISTORY OF MODERN URBAN DRAINAGE IN BARCELONA

Garcia Faria and the creation of the first modern sewer network in Barcelona

UrbanizationUrbanisation and water supply and drainage are deeply interwoven factors in the history of cities. The expansion or urbanisation often disrupts natural drainage patterns while soil sealing reduces infiltration capacities. According to Karvonen (2011), rainwater and stormwater evacuation outlets, despite being many times the oldest networks in certain cities, have received historically much less attention in engineering than supply or wastewater networks. The philosophy of 'out of sight, out of mind' (Zhou, 2014) also influenced the convenience of mixing these flows with those of wastewater under what became known as combined sewers. All in all, the increasing separation between nature and culture brought about by the transit from the organic city to the functional city (Gandy, 1999) paralleled the creation of large infrastructures and also of a specialised large managerial class able to command and control the new networks built to accommodate unwanted water flows (Cousins, 2016).

This approach of combined sewers, best exemplified by Paris in the mid-19th century, will be taken up by many European cities including Barcelona. Since the first sewers built in Roman times, Barcelona had created a drainage system that served most of the city contained within the walls of the 14th century and took advantage of the several perennial small streams ('*rambles*' or *torrents* in Catalan) flowing towards the sea (Ajuntament de Barcelona, 1991). In the mid-19th century, however, the city had become overcrowded and ridden with disease. Cholera epidemics in 1865 and again in 1885 had killed thousands (Corbella, 1989). The medieval walls had been torn down in 1854 but conditions of insalubrity within the city remained unabated. With densities approaching 800 persons per hectare and poor sanitary conditions, mortality in Barcelona was higher not only than in Paris or London but than in Mumbai and Calcutta as well (Nadal, 1987). A grandiose urban plan for city expansion was designed by engineer Ildefons Cerdà and finally approved by the City Council in the 1860s (Magrinyà, 2008; Permanyer, 2008). This plan, however, lacked a counterpart in water supply and sanitation terms, which was delayed until two decades later.

Engineer Pere Garcia Faria prepared a sanitation plan that was approved by the Barcelona City Council in 1891 (Arandes, 1980; Miranda, 2006). Under the name of Plan for the Reform of Sewers and Sanitation of the Underground of Barcelona, the plan envisaged the extension of the sewer network to more than 200 km from the original 30 km. Also, it ensured the continuity of flows in the system by forcing consumptions of a minimum of 60 litres/person/day in buildings (Irigoyen, 1990). Again as in Paris, the supply of running water and the supply of a sanitation network went hand in hand since without a minimum water flow the system would not work properly. At that time, water supply in the city was subject to an intense process of reorganisation by companies with the final consolidation of the *Sociedad General de Aguas de Barcelona* in 1882 (Martin, 2009). Thus urbanisation, water supply and water drainage formed part of the same dynamics (Swyngedouw, 2004) and a large, complex and expanding water system would ensure urban growth during the following decades (Masjuan et al., 2008).

Garcia Faria wanted rainwater and wastewater removed from Barcelona, and especially from the city beaches which at the turn of the 20th century were becoming more and more valued by Barcelona citizens. According to the plan, unwanted flows carried away by a specific transportation system called 'train', would be a final and useful destination in irrigating the agricultural fields of the nearby Llobregat Delta. The requirements by the city council, namely the combined sewer system for rainwater and wastewater; connection points for every building, and natural ventilation through gutters, were met by the Garcia Faria plan. Moreover, pipes were also designed to release wastewater far into the sea. Garcia Faria's approach resembled that adopted in Berlin where, contrary to London or Paris, for instance, wastewater was not discharged downstream of the city but directed to agricultural areas (Moss, 2000).

In the end, however, the Garcia Faria Plan did not accomplish many of its objectives. As happened in Paris, the provision of running water to buildings critical for the correct operation of the sewer system did not materialise fast enough. Moreover, wastewater never reached the Llobregat Delta and could not be used in irrigation. In fact, most of the sewers ended in the Southeast of the city, in a beach area known as Bogatell, which became one of the endemic flood and pollution hot spots during the first half of the 20th century (Tarragó et al., 1986).

The expansion of the sewer network during the 20th century

In 1954 the General Plan of Sanitation and Sewers for Barcelona was approved just a year after the Urban Plan of 1953 (Ajuntament de Barcelona, 1991). Basically the new sanitation plan represented a continuation of Garcia Faria's and focused on the construction of new and larger sewers and pipes to convey unwanted water to the sea. The use of wastewater for irrigation of the agricultural area of the Llobregat Delta was abandoned although, in the following year, a project to use reclaimed wastewater in a more distant agricultural area north of the city was considered.

Between 1950 and 1970, the population of Barcelona increased by more than half a million. The arrival of migrants from other parts of Spain accelerated the urbanisation process in not only in the more rugged terrains of the Northern and North Eastern peripheries of the city but also in low-lying areas of the Llobregat River floodplain (Capel, 2005). Urbanisation of these peripheral areas as well as of the satellite towns always proceeded ahead of the construction of critical infrastructures including a sewer system able to absorb increasing stormwater and wastewater flows from the new developments (Borja, 1972). Furthermore, industrial development during the 1950s and 1960s had left a heavy toll on

Table 1. Urban drainage in Barcelona: Summary of the main planning documents (1891-2009).

Name of the plan	Year	Geographical scope	Main approach	Main features
Project for the Sanitation of the Barcelona underground ('Garcia Faria Plan')	1891	Barcelona	Based on Paris' "everything down the sewer". Combined stormwater and wastewater system Rapid evacuation of stormwater and wastewater flows from the city	200 km of new sewers 'Wastewater train' to irrigate the agricultural area of the Llobregat Delta (disregarded)
General Plan for Sewerage and Sanitation of Barcelona	1954	Barcelona	Same as above	Expansion and consolidation of main sewers Connection to the sewer system of neighbourhoods still using septic tanks Covering of urban waterways Release of wastewater and stormwater flows to the sea after treatment with chlorine (not implemented)
Special Plan of Sanitation and Sewage ('Vilalta Plan')	1968	Barcelona	Less focus on drainage and more on the construction of wastewater treatment plants and water reuse to reduce the impact of episodes of water stress	Expansion and improvement of the sewer network Construction of the wastewater treatment plants of Besos and Bogatell
Sanitation Plan of the Metropolitan Corporation of Barcelona	1981	Metropolitan Area of Barcelona (27 municipalities)	Same as 'Vilalta Plan'. Emphasis on the environmental recovery of the metropolitan beach front	Expansion of the sewer network (metropolitan scale) Construction of wastewater treatment plants Innovative projects for water reuse (i.e. groundwater recharge in the Llobregat Delta to contain seawater intrusion)

Special Plan for Sewerage in Barcelona	1988	Barcelona	Testing of the performance of the sewer network through computer programming attempt to provide a definitive solution to flooding and pollution problems of the beach front where the new Olympic Village was to be built	100 km of new sewers; massive reorganization of the sewer system into two main, high-capacity drains: The eastern drain (Bogatell) and the western drain (Llobregat). Environmental rehabilitation of the beach front near the Olympic Village
5th Special Plan for Sewerage in Barcelona	1997	Barcelona plus two nearby cities	Focus on flooding 'hot spots' in the urban area and enforcement of the European Urban Wastewater Directive	First underground storage reservoirs for stormwater. Two large drains extended until the expanded and improved wastewater treatment plant of Besòs and the new wastewater treatment plant of the Llobregat are completed.
Master Plan for Rainwater of the Metropolitan Area of Barcelona	2003	Metropolitan area (27 municipalities)	Revision in depth of the drainage system at the metropolitan level Interest in regulating the quality of rainwater flows	Construction of retention areas and land use controls for rainwater sewers affected by heavy pollution loads
Integrated Plan for Sewerage in Barcelona	2006	Barcelona	Focus on diffuse flooding Interest in developing 'techniques for sustainable urban drainage'	Strong expansion of the programme for building underground stormwater reservoirs
Plan for the Development of Alternative Water Resources in Barcelona	2009	Barcelona	Part of the 'Sustainability Objectives' of the City Council. Impact of several drought periods (the latest and more severe being that of 2008; strong emphasis on local groundwater; rainwater harvesting or treated wastewater not considered	Alternative resources to be used by públic, non-potable uses Development of first SUDS in public parks, streets and residential projects (all at small scale) Programme of Vertical Gardens using harvested rainwater (but as part of the city Biodiversity and Green Planning)

the city sea front and beaches in particular suffered from intense degradation since flows were released to the sea without any treatment.

In 1968, a new Water Sanitation Plan was approved by the city council (Vilalta, 1968). Urban growth had exacerbated the problem of flooding and pollution in the city due to increasing rates of soil sealing and to the disturbance of natural drainage patterns. Moreover, the infrastructure required for other flows (gas, electricity, etc) often interfered with the sewer system causing alterations and worsening the flood problem. The latter, on the other hand, was made worse due to the expansion of the subway system and the construction of underground garages and parking lots which increased considerably in the city as the number of vehicles had risen sharply in the 1960s.

The plan of 1968 put a special emphasis not so much on drainage (about 20% of total projected investment) but in the construction of wastewater treatment plants. According to the plan the construction of these plants was necessary not only to remove pollution from the sea front of the city and recover the beaches but also to reuse water in order to lessen the water supply deficits of Barcelona and its Metropolitan area (Vilalta, 1968). Costs of the plan were to be financed with a new and specific water tax following the experience in this regard by other European countries. Nevertheless, the plan could not be implemented in full due to financial constraints and lack of political interest. Sewers continued their expansion following the path of urban growth but the construction of new or improved wastewater treatment plants had to wait at least two decades. At any rate, the 1968 Plan was the first serious attempt at improving water sanitation in Barcelona since the times of Garcia Faria.

In the early 1980s most sewers in the Metropolitan Area of Barcelona released untreated wastewater directly to the Llobregat and Besòs river basins and the sea while treatment in the Bogatell and Besòs plants covered 70% of wastewater. Flooding remained a major problem due to insufficient capacity and/or conservation of drainage systems; more damaging events were linked to urbanisation and soil sealing and overstressed sewers carrying wastewater and rainwater. The 1981 Plan, again, attempted to offer solutions to all these challenges by widening the scale of action in order to cover not only Barcelona but also the Metropolitan Area formed by 27 municipalities (Arandes, 1981). The plan developed a number of proposals from a survey addressed to the 27 municipalities of the Barcelona Metropolitan Area regarding deficits in drainage systems. The plan also considered reusing treated wastewater for irrigation as well as for groundwater recharge and possibly for certain industrial uses subject to results of various studies on water quality requirements. One of the most innovative projects arising from this plan was to inject treated wastewater into the southern aquifer of the Llobregat Delta to prevent intrusion of seawater (Ortuño et al., 2009).

During this period, therefore, the city had followed the stages in the model by Brown et al. (2009) from supply to sanitation and to drainage. However, successive plans remained far from achieving the objectives expressed in the plans. Flooding and public health (especially in terms of pollution of the beach front) had grown to become metropolitan problems while water supply faced scarcity threats produced by recurrent droughts (March and Saurí, 2013). In 1986, Barcelona was selected to host the Olympic Games of 1992. This event would change the city in important ways, not the least in what concerned its drainage network.

Change, consolidation and limitations of a large-scale sewer system: The Olympic Games of 1992

The Olympic Games of 1992 entailed the most important operation of urban renewal in Barcelona since the Universal Fair of 1929. The most important target was the Eastern part of the seafront, then a degraded area chronically ravaged by floods and pollution. Drainage became one of key components of Olympic project because the seafront was selected as the area to build the so-called Olympic Village, an entirely new urban development that would become one of the more attractive (and expensive) residential areas of the city. For urban drainage, the Olympic Games could be seen as inaugurating the transition towards the 'water sensitive city' of Brown et al. (2009). Perhaps equally important was the European Wastewater Directive of 1991 (European Commission, 1991) which forced city planners and managers to tackle once and for all the endemic problem of pollution and degradation of the beach front. The conventional drainage system was not questioned by any means but at least some symptoms of change towards more sustainable solutions began to take place, especially regarding wastewater treatment.

In 1988 and with the Olympic Games fuelling a major redevelopment of the city seafront, the city council passed a new plan to extend and update the city sewer system still unable to accommodate medium and large flood events (Ajuntament de Barcelona, 1988). Flooding again was the main issue and there was a pressing need to redesign and enhance the capacity of drains and sewers for increasingly short return periods (10 years) of heavy precipitation. Massive investments in reorganising and changing the sewer network, particularly in the maritime front followed (Vila Olímpica, 1990). The 1988 plan acknowledged the deficit in sewers and drains and, faithful to the centralised view, proposed a reduced number of large systems rather than a larger number of small systems. It also included for the first time the construction of underground stormwater-retention reservoirs.

The reduction of flows arriving at the area of the Olympic Village through the Bogatell sewer was accomplished by redirecting flows to other outlets. Hence the risk of flooding and pollution of the beaches was minimised and the city gained a sizeable beach space which would play a major role in the revitalisation of previously degraded areas. These, in turn, were targeted by real estate and tourist interests (Delgado, 2007). While the Olympic event of 1992 provided the solution of the flooding problems of the Poble Nou many parts of the city still suffered from periodic inundation. In 1997, a new plan identified these problematic areas and analysed the causes of flooding using a combined computer model of extreme precipitation events and sewer capacities which could deliver data in real time (Ajuntament de Barcelona, 1997). The plan not only included Barcelona but also other municipalities of the Metropolitan area such as l'Hospitalet, Esplugues de Llobregat and parts of Sant Adrià del Besòs. The extension and reorganisation of the sewer system proposed by the 1997 plan also opted for a model based on a small number of big operations that involved the construction of two large storm drains at both extremes of the city connected to wastewater treatment plants.

The most distinctive characteristic of the 1997 plan was, however, the construction of underground water-retention reservoirs in several areas of the city known for their flooding problems. Reservoirs were designed with the basic objective of reducing and controlling the release of polluted flood flows downstream the system in order to alleviate frequent and damaging overloads in wastewater plants. On the other hand, part of the pollution was captured in the reservoirs by sedimentation processes. In 2015, there were 12 such reservoirs (plus two open-air facilities) in the city holding a combined storage capacity of about 500,000 cubic metres (m^3) of water.

After controlling floods and pollution and thus securing flows in ways not foreseen just a few decades ago, the next step in drainage and wastewater management was to recycle and, if possible reuse, unwanted flows in order to comply with European regulations, and especially the Urban Wastewater Directive of 1991. In Barcelona, as said before, mixed stormwater and wastewater was directed towards two large wastewater treatment plants, in which the water is treated and almost all released to the sea. Water reuse from these plants is still comparatively small despite the fact that water quality measured at the point of release of treated flows is equal or even higher than that of the Llobregat and Besòs rivers. In fact, during the drought of 2008, it was proposed to pump treated flows from the Llobregat plant upstream the river to approximately 8 km before the water purification plant of Sant Joan Despí, serving half the population of the Metropolitan Area, because of the argument that the river would complete the treatment process and water arriving at the plant would be ready for treatment. This idea was abandoned once the drought ended but it was considered again in 2016 given the generally good quality of the effluent and the smaller costs of treatment compared for instance with desalinated water (El Periódico, 2016). Currently, flows treated in the Llobregat plant are used for irrigation, and also for groundwater recharge in part to prevent intrusion of seawater. In the Besòs plant, water is reused for agricultural and environmental functions.

The approach taken by the 1997 plan for the city of Barcelona inspired the Metropolitan Rainwater Plan of 2003 by which the 33 municipalities of the Metropolitan Area of Barcelona (with a population of 3 million) revised their drainage systems in depth. One particular problem affected municipalities with separate networks that directed rainwater often carrying high pollution loads to fluvial courses or the sea. The plan proposed the construction of retention ponds for these flows as well as land use controls to avoid flooding, which constituted a first step in the direction of regulating not only the quantity but also the quality of stormwater flows (EMSHTR, 2003).

The 2000s: A turning point in drainage management? Local aquifers and SUDS

Since 1997 considerable progress has been made in the generation of hydraulic data and in the knowledge on the behaviour of the sewer network. At the same time, significant changes have occurred regarding large infrastructures such as new metro lines and the new underground high speed train line. Also, certain neighbourhoods have been subjected to redevelopment with consequences for the sewer system. Finally, new water-related European Directives emphasising environmental protection of receiving bodies requiring stringent standards in water quality have been passed and enforced. Still, the transition towards the 'water cycle city' and the 'water sensitive city' of Brown et al. (2009) has been plagued with problems. By 2006, the sewer network had expanded to more than 2000 km but some problematic issues remained, especially the protection of beaches in face of pollution loads generated by intense rainfall. This implied excessive pressure on the Barcelona beaches particularly the risk of not meeting European directives on quality of bathing waters.

In 2006, a new sewer plan was approved by the city council. The most important feature of this plan was the decision to expand the previous policy of fighting diffuse pollution associated with rainfall with the construction of new underground stormwater reservoirs. However, in what would be the first seeds of the 'water sensitive city', the plan also proposed to develop "techniques for sustainable urban drainage". This particular proposal was labelled as 'experimental' and aimed at reducing the amount and pollution associated with stormwater entering the system. In the linear organisational scheme of the sewer network (that is, upstream the network; points of entry into the network; network; wastewater treatment plant and receiving body) these techniques were to be located in the first phase previous to the capture of flows by sewers. The plan warned, however, that new techniques were 'experimental actions' and adopted the term of Sustainable Urban Drainage Systems (SUDS) to refer to systems that managed runoff processes under the principles of storage, reduction of impervious surfaces and infiltration as well as for the reuse of rainwater. The plan, however, did not foresee any funding for the application of these techniques and much less envisaged the possibility of replacing at least parts of the traditional network of drains and sewers with SUDS.

The recovery of local aquifers

While the poor quality of stormwater and wastewater flows that accumulated in underground reservoirs precluded their use before extensive treatment, the water in local aquifers fared better. Located on a plain backed by a mountain range, Barcelona had been traditionally rich in groundwater (Ajuntament de Barcelona, 1998) but decades of industrialisation and urbanisation had severely polluted this resource. However, with industrial decline and better sewerage, water tables recovered and began to create flooding problems in the metro system and other underground infrastructures (Parés et al., 2006).

Local groundwater constituted the backbone of the 2009 Plan for the Development of Alternative Water Resources in Barcelona. The plan has to be contextualised within the growing interest of the city for sustainability issues and the approval in 2002 of the Citizen Commitment for Sustainability. The plan emphasised the need to use alternative sources of water in order to reduce the pressure on the Ter-Llobregat Reservoir system which supplies up to 70% of the water to Barcelona. The European Water Framework Directive of 2000 with its emphasis on good quality of water environments and the integrated view on water management also influenced the adoption of this plan. Moreover, the city had to prepare for future droughts even though a desalination plant with a capacity of 60 cubic hectometres was inaugurated in 2009 to complement the more uncertain supply of the Ter-Llobregat reservoirs (March and Saurí, 2013).

The plan stated as its general objective the development of alternative water resources (local groundwater, rainwater, and treated wastewater from the wastewater plants) for their use in the irrigation of municipal parks and gardens with consumptions above 3,000 cubic metres/year (m^3/yr); street cleaning; cleaning and irrigation of sport fields and other facilities; tanks for the cleaning of sewers; lakes and ornamental fountains as well as other large emblematic facilities such as the city zoo. Private facilities and supply to the domestic sphere were explicitly excluded from the list of potential uses.

The plan quantified the amount of these alternative resources in 16.5 cubic hectometres of water per year. Only 6% of this quantity was actually used and all came from the local aquifers. Despite being mentioned in the introduction, the plan finally explicitly excluded stormwater from the alternative resource matrix. The reasons given to justify this option were basically three. First, the need to store stormwater in tanks and/or reservoirs relatively large in size and therefore costly; second, the poor quality of water coming from urban runoff requiring expensive treatments, especially as is the case in the city, when stormwater is mixed with wastewater. Finally, reuse of water from the underground reservoirs addressed to store stormwater was further complicated by the fact that these reservoirs should be emptied as soon as possible to release storage for the next storms.

First steps in the implementation of SUDS

Although the 1997 Sewer Plan had already introduced recommendations for the implementation of sustainable urban drainage techniques, the first projects did not appear until 2004 and were promoted not by CLABSA (the municipal company in charge of urban drainage, now BCASA or *Barcelona Cicle de L'Aigua*) but by BAGURSA or *Barcelona Gestió Urbanística* (another municipal company in charge of redevelopment and rehabilitation of city neighbourhoods). Professionally, these projects also certified the emergence of new actors in drainage planning, especially landscape architects. The first two development projects in the city in which SUDs figured prominently were the Joan Reventós Park and the low-income Torre Baró neighbourhood (Soto, 2016). Currently, SUDS can be found in urban renewal projects (as in the Can Cortada, Torre Baró or Bon Pastor Neighbourhoods) or in leisure areas (Joan Reventós Park).

SUDS, however, still remain far from consolidation as an active option regarding urban drainage. For example, 90% of the current SUDS projects in the city are led by the same landscape architect from BAGURSA who had to face certain attitudes of mistrust by BCASA. For example, in one project involving the implementation of a SUD system, BCASA forced the replication of this system using conventional drains connected to the sewer network because it considered that the security provided by the SUD in case of flooding was insufficient.

Criticisms of SUDS have been common. Critics tend to emphasise issues such as maintenance of the system and the administrative nature of management responsibilities; in other words, who would be held responsible if a SUD system cannot properly contain flood-producing damages. SUDS have also been a terrain of debate between two different management cultures in urban drainage: the culture of engineers emphasising the overarching goal of risk reduction, and the culture of landscape architects with a greater interest in environmental issues. However, mutual mistrust appears to be receding and, since 2014, a working group on SUDS has been created by the Garden and Park Service of the Barcelona city council with participation of both BCASA and BAGURSA. This working group (formed by eight people, half of whom are from the City Service on Green Areas and Biodiversity) has produced a blueprint of 'good practices' aimed at the more formal introduction of SUDS in plans for the construction of renovation of parks and other public spaces in the city. In 2017, the city is expected to have a full Technical Plan for SUDS in Barcelona (Martí, 2016).

All these projects show the emergence of the 'water sensitive city' period in Barcelona marking the transition from conventional drainage solutions based on centralised, large-scale networks to more distributed, small-scale, more sustainable solutions. However, as we will discuss in the next section their future development would likely remain limited while, on the other hand, large systems may themselves pursue their own sustainability paths.

DISCUSSION AND CONCLUSIONS

This review of the history of drainage and drainage-related projects in Barcelona raises in our opinion several questions of potential interest for studies on the transition of urban water management towards sustainability. First, the Barcelona case may be a good illustration of steps taken towards the 'water sensitive city' which, according to Brown et al. (2009) would represent the pinnacle of the sustainability transition. From the initial plan of Garcia Faria in the 19th century to the current initiatives for developing SUDS and other initiatives regarding the capture and reuse of rainwater the progress appears to be small but evident. However, the obduracy (Moss, 2016) of conventional systems has been strong enough to reduce the water-sensitive city to a number of small and dispersed projects linked to relatively modest operations of urban renewal while the bulk of the drainage system remains, based on the conventional system. Although many cities worldwide are introducing the water sensitive approach, only Melbourne is cited as a clear example of the relevance of this approach and even so, at best, for some, in integration with the conventional system (Grant et al., 2013). For others, however, the Melbourne case provides an unrealistic view of the planning process, much 'muddier' than depicted in the accounts of the water-sensitive city proponents (Furlong, 2016; see also Molle, 2008). In Barcelona, hurdles to the full development of the water-sensitive city also exist and are important.

Another issue of interest in the Barcelona case is whether large, centralised systems are irremediably unsustainable. If water reuse is considered one pillar of the circular economy and therefore of sustainability, then this is not so new as some early drainage projects had already this objective in mind. In Barcelona, the Garcia Faria plan foresaw the utility of wastewater for irrigated agriculture (as in Berlin; see Moss, 2000). The Vilalta plan of 1968 also envisaged wastewater treatment and reuse while the current wastewater treatment plants, built after the mandate of the European Urban Wastewater Directive of 1991, can produce water of enough quality for a wide variety of uses including (indirectly) human consumption. To a certain extent, the literature on urban drainage transitions has helped to reproduce an image of the conventional systems as obsolete, unsustainable, and unable to solve flooding and pollution problems (Zhou, 2014; Carlson et al., 2015). While this view may be right in many cases it also tends to downplay changes within these systems themselves that may indicate more interest in sustainable approaches than are usually thought, especially given the growing opportunities for wastewater reuse.

Third, transition theory has also been criticised for not paying enough attention to the geographical and historical contexts in which sustainable paths develop. In this regard, the physical and human geography of the Barcelona area (a relatively narrow plain between a mountain range and the sea; steep slopes, extreme precipitation events, and urbanisation processes producing high population densities) greatly influenced the development of a centralised sewer network combining stormwater and wastewater. The history and geography of these physical and human factors, and particularly of an urbanisation process based for many decades on a fast and unplanned growth, have made it very difficult to consolidate a water-sensitive city, based on distributional, small-scale drainage systems.

Therefore, the enhancement of the sewer network (in extension and capacity) has progressed as part of the more general relationship between urbanisation and the water cycle. Given the scarcity of urban land in the city, especially during the 1960s and 1970s, the built environment expanded in the nearby towns reproducing the same drainage problems (and the perennial flooding problem) in the new built up areas. The large urban renewal projects of the 1990s and the 2000s (especially the Olympic Village) never considered a change in approach regarding drainage and instead they opted for reinforcing the conventional systems by building larger sewers and related infrastructure in order to enhance protection of environmental quality (most notably the beach front) of an area in which environmental quality was rapidly captured by gentrification processes. Hence and as said before, the transition to the water-sensitive city, at least in the Barcelona case, is hampered by urban geographies and histories that at the very best allow for a very limited coexistence of both drainage options while producing inequalities in terms of access to environmental amenities.

Fourth, the Barcelona case is also interesting because the transition towards the water-sensitive city shows a reconfiguration of governance in urban drainage (Boss and Brown, 2012). The transition towards sustainable urban drainage necessitates both technological and socio-institutional change, especially in what concerns management cultures. In the case of Barcelona we can not only observe the initial reluctance to SUDS by conventional drainage professionals, but also the very important role played by individual frontrunners (Rotmans and Loorbach, 2009) in the transition towards the water-sensitive city. SUDS in Barcelona owe a great deal to a single landscape architect who is behind almost all projects currently being developed in the city and who has successfully convinced earlier critics (especially BCASA engineers) of the potential of such systems. Moreover and in agreement with interdisciplinary nature of alternative systems collaboration (not always easy) between different departments of the city council, in our case, parks and gardens, urban landscape, and urban water cycle has been formalised through the creation of a task force on SUDS.

Finally and somehow not always sufficiently emphasised by the proponents of the water-sensitive city, SUDS and related systems create not only new areas in the urban fabric that may contribute to (environmental) sustainability objectives but also spaces of social interaction (Karvonen, 2011). In Barcelona, SUDS in parks and in rehabilitated neighbourhoods integrate drainage functions with these functions of social interaction. Hence the 'water-sensitive city' may also become a renewed arena for the enhancement of citizenship values.

In conclusion, future steps towards a more circular and therefore more sustainable pattern of the urban water cycle in Barcelona will surely involve more SUDS and vertical garden projects detracting rainwater and stormwater before it mixes with wastewater in the sewer system, especially in urban renewal plans. However, it is highly unlikely that these projects will represent a substantial change in the current dominant structure of urban drainage in the city which in terms of hazard (flooding) reduction can claim now a relatively safe condition. The transition towards the water-sensitive city would not be complete without the transformation of urban runoff into a resource. However, indirectly this function may be performed with the large and centralised wastewater treatment plants (and the subsequent reuse of effluents) associated with conventional systems. More directly and perhaps less costly, the same function could be performed by SUDS. Perhaps then, as the Barcelona case appears to suggest, the transition towards the water-sensitive city would not imply the substitution of one approach for the other but rather the coexistence of both.

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