UNIVERSITAT POLITÈCNICA DE VALÈNCIA

DEPARTAMENTO DE INGENIERÍA HIDRÁULICA Y MEDIO AMBIENTE

PROGRAMA DE DOCTORADO DE INGENIERÍA DEL AGUA Y MEDIOAMBIENTAL

TESIS DOCTORAL

A REGENERATIVE URBAN STORMWATER MANAGEMENT METHODOLOGY.

THE ROLE OF SUDS CONSTRUCTION AND MONITORING IN THE TRANSITION OF A MEDITERRANEAN CITY.

AUTOR:

CARMEN SARA PERALES MOMPARLER

DIRECTORES:

JOAQUÍN ANDREU ÁLVAREZ

IGNACIO ANDRÉS DOMÉNECH

OCTUBRE 2015 - VALENCIA (ESPAÑA)

"Don't go through life,

grow through life"

Eric Butterworth

ACKNOWLEDGEMENTS

I would like to dedicate this thesis to my husband, Iñaki, for his unconditional support, at home and abroad.

I am grateful to my thesis directors, Dr. Joaquín Andreu and Dr. Ignacio Andrés, for their guidance throughout the process. My special thanks to the latter, for all the fun moments we have enjoyed in between the hard work.

A special mention of professor Chris Jefferies, to whom I am thankful for the orientation he has provided all along my career, both at the academic and the professional levels. Thanks also to Dr. Sue Charlesworth, for all that I learned during my stay at Coventry University.

A warm gratitude to Susan Dodson, for her friendship and the time she has dedicated to improving the English grammar of my publications.

And a special thanks to my parents, Carmen and Antonio; to my “new” parents, Maria and Roberto; and to Amparo, for transmitting their energy and believing in me.

Last, but not least, a special mention to my offspring Pablo and Ana, who are happily accompanying me in the last part of this project.

ABSTRACT

Under the well-known slogan 'think global, act local', cities in the 21st century face the enormous challenge of catalyzing, intensifying and accelerating sustainable urban transformations. Without losing a holistic view, the methodology presented in this thesis places the focus on 'resource management and climate mitigation and adaptation', in particular in urban stormwater management, proposing processes that can bring about the required change, shaped by the place-based approach of the regenerative sustainability paradigm.

Building upon literature and practice that supports a flexible approach to stormwater management in urban environments that mimic natural processes and predevelopment hydrology (Sustainable Drainage Systems, SuDS) as one way to, amongst others, help to prevent and adapt to climate change, the thesis highlights the relevance of the connection to the place for adoption of best practices that conduct towards a regenerative system. Hence, it incorporates this connection to the place to the SuDS representation, naming it the SuDS 'landed rocket'.

The proposed methodology includes a conceptual framework, specific method and tools, that allows for the understanding and the characterization of the current situation of a urban stormwater system in a process that guides future actions to move towards the desired regenerative urban built environment concept, with a place-based holistic view.

This methodology has been applied to Benaguasil, a Mediterranean city, where stormwater management is the local authority's responsibility and has been historically guided by mainstream conventional drainage practices. The thesis shows how, by taking a multi-dimensional and trans-disciplinary approach to solve environmental problems, future actions can be properly addressed. Working with academia has been essential to develop wider evidence base. In this case, a sequence of research projects has advanced the innovative approach to stormwater management in Benaguasil, but it is contended that this methodology could be applied to any urban context.

The thesis aims to enhance smart governance by providing information about the successful implementation and monitoring of SuDS showcase sites in Mediterranean Spain. These showcase sites are catalysts in the transition towards regenerative urban built environments in the region. In addition, it provides international examples that add further credence for improved urban ecological infrastructure by demonstrating what success can look like.

RESUMEN

Bajo el conocido eslogan ‘piensa global, actúa local’, las ciudades del siglo XXI se enfrentan al gran reto de catalizar, intensificar y acelerar las transformaciones hacia un urbanismo sostenible. Desde una perspectiva holística, la metodología presentada en esta tesis se centra en ‘la gestión de los recursos y la adaptación y mitigación al cambio climático’, en particular en la gestión de las escorrentías urbanas, proponiendo los procesos que pueden ayudar al cambio requerido, bajo el enfoque del paradigma de la sostenibilidad regenerativa local.

A partir de las referencias bibliográficas y experiencias que avalan a los Sistemas de Drenaje Sostenible (SuDS) como enfoque flexible a la gestión de las escorrentías urbanas, tratando de mimetizar los procesos hidrológicos previos al desarrollo urbano (que entre otros, contribuyen a la prevención y adaptación frente al cambio climático de las ciudades), la tesis subraya la relevancia de la conexión con el lugar para la selección de las mejores soluciones que lo conduzcan hacia un sistema regenerativo. Así, se incorpora esta conexión con el lugar a la representación de los SuDS, dándole el nombre de ‘SuDS landed rocket’.

La metodología propuesta incluye un marco conceptual, un método y herramientas específicas que permiten el entendimiento y caracterización de la situación actual de un sistema de drenaje urbano en un proceso que guíe acciones futuras para progresar hacia el concepto del medioambiente urbano regenerativo deseado, con una perspectiva holística local.

La metodología se ha aplicado en Benaguasil, una ciudad mediterránea, donde la gestión del agua de lluvia es responsabilidad local y que ha estado influenciada históricamente por prácticas convencionales de drenaje. La tesis muestra cómo adoptando un enfoque multidimensional y multidisciplinar para resolver problemas medioambientales, las acciones futuras se pueden plantear correctamente. El trabajo con las instituciones académicas se ha demostrado esencial para desarrollar evidencias de base más amplias. En este caso, una serie de proyectos de investigación ha permitido el avance de Benaguasil hacia una gestión del agua de lluvia más innovadora. La experiencia demuestra que la metodología podría ser aplicada a cualquier otro contexto urbano.

La tesis pretende mejorar la gobernanza inteligente proveyendo información respecto de la implementación y monitorización exitosas de SuDS en experiencias piloto en la España mediterránea. Estas demostraciones son catalizadoras de la transición hacia un medio ambiente urbano regenerativo en la región. Además, presenta ejemplos que se añaden al catálogo internacional de experiencias, mostrando el camino del éxito hacia un entorno urbano más saludable y habitable.

RESUM

Sota el conegut lema 'pensa global, actua local', les ciutats del segle XXI s'enfronten al gran repte de catalitzar, intensificar i accelerar les transformacions cap a un urbanisme sostenible. Des d'una perspectiva holística, la metodologia presentada en esta tesis es centra en 'la gestió dels recursos i la adaptació i mitigació al canvi climàtic', en particular en la gestió de les escorrenties urbanes, proposant processos que poden ajudar al canvi requés, des d'una òptica del paradigma de la sostenibilitat regenerativa local.

A partir de les referències bibliogràfiques i experiències que avalen els Sistemes de Drenatge Sostenible (SuDS) com una aproximació flexible a la gestió de les escorrenties urbanes, tractant de mimetitzar els processos hidrològics previs al desenvolupament urbà (que entre altres, contribueixen a la prevenció i adaptació al canvi climàtic de les ciutats), la tesis subratlla la rellevància de la connexió al lloc per a la selecció de les millors solucions que el puguen conduir cap a un sistema regeneratiu. D'esta manera, s'incorpora esta connexió al lloc en la representació dels SuDS, donant-li el nom de 'SuDS landed rocket'.

La metodologia proposta inclou un marc conceptual, un mètode i unes eines especifiques que permeten l'enteniment i caracterització de la situació actual d'un sistema de drenatge urbà en un procés que guie accions futures per a progressar cap al concepte de medi ambient urbà regeneratiu desitjat, amb una perspectiva holística local.

La metodologia s'ha aplicat a Benaguasil, una ciutat mediterrània, on la gestió de l'aigua de pluja és responsabilitat local, i que ha estat influenciada històricament per pràctiques convencionals de drenatge. La tesis mostra com adoptant un punt de mira multidimensional i multidisciplinari per a resoldre problemes medi ambientals, les accions futures es poden plantejar correctament. El treball amb les institucions acadèmiques s'ha demostrat essencial per a crear evidències de base més amples. En este cas, una sèrie de projectes europeus d'investigació ha permès l'avanç de Benaguasil cap a una gestió de l'aigua de pluja més innovadora. L'experiència demostra que la metodologia podria ser aplicada a qualsevol altre context urbà.

La tesis pretén millorar la governança intel·ligent aportant informació respecte de la implementació i monitorització exitoses de SuDS en experiències pilot en la Espanya mediterrània. Estes demostracions son catalitzadores de la transició cap a un medi ambient urbà regeneratiu en la regió. A més a més, presenta exemples que s'afegeixen al catàleg internacional d'experiències, mostrant el camí del èxit cap a un entorn urbà més saludable i habitable.

TABLE OF CONTENTS

Acknowledgements

Abstract

Resumen

Resum

1. INTRODUCTION **1**

1.1. RESEARCH MOTIVATION 1
1.2. OBJECTIVES 5

2. PUBLICATIONS **7**

3. RESULTS AND DISCUSSION **9**

3.1. A REGENERATIVE URBAN STORMWATER MANAGEMENT METHODOLOGY 9
3.2. URBAN STORMWATER MANAGEMENT IN BENAGUASIL: THE JOURNEY 16
3.3. THE ROLE OF SUDS CONSTRUCTION AND MONITORING AS TRANSITION CATALYZERS 25

4. CONCLUSIONS **27**

4.1. FINAL REMARKS 27
4.2. FUTURE RESEARCH PATHWAYS 28

5. REFERENCES **29**

ANNEXES **37**

ANNEX 1: ***A REGENERATIVE URBAN STORMWATER MANAGEMENT METHODOLOGY: THE JOURNEY OF A MEDITERRANEAN CITY.*** 39
ANNEX 2: ***SUDS EFFICIENCY DURING THE START-UP PERIOD UNDER MEDITERRANEAN CLIMATIC CONDITIONS.*** 71
ANNEX 3: ***THE SUSTAINABLE MANAGEMENT OF SURFACE WATER AT THE BUILDING SCALE: PRELIMINARY RESULTS OF CASE STUDIES IN THE UK AND SPAIN.*** 91
ANNEX 4: ***THE ROLE OF MONITORING SUSTAINABLE DRAINAGE SYSTEMS FOR CATALYZING TRANSITION TOWARDS REGENERATIVE URBAN BUILT ENVIRONMENTS: A CASE STUDY IN THE VALENCIAN REGION, SPAIN.*** 107
ANNEX 5: ***ANÁLISIS COMPARATIVO DE LAS ESCORRENTÍAS PRODUCIDAS EN UN PAVIMENTO PERMEABLE Y EN UNA CALZADA CONVENCIONAL.*** 133
ANNEX 6: ***INNER-CITY SUDS RETROFITTED SITES TO PROMOTE SUSTAINABLE STORMWATER MANAGEMENT IN THE MEDITERRANEAN REGION OF VALENCIA: AQUAVAL (LIFE+ EU PROGRAMME).*** 143

1. INTRODUCTION

1.1. Research motivation

Urban drainage patterns are altered by increasing urbanization and soil sealing, leading to increased flood risk and diminish of aquifer recharge (European Commission, 2012). Traditional practice in many countries considers urban stormwater as a waste product instead of a precious resource, and its rapid conveyance and discharge contributes to the degradation of receiving waterways: combined sewer overflows (CSOs), diffuse pollution, etc. (Andrés-Doménech et al., 2010; Campbell et al., 2004). These effects are expected to escalate with climate change: extreme rainfall changes in the range 10-60% may lead to changes in flood and CSOs frequencies and volumes in the range 0-400% depending on the system characteristics (Willems et al., 2012); action cannot be further delayed and needs to be taken with an adaptive approach that involves, in addition to investments, active learning and consideration of the interrelationship of the economic and social challenges facing cities around the world (Arnbjerg-Nielsen et al., 2013; Gasper et al., 2011).

In response, a relatively new and flexible approach to urban stormwater management has emerged that makes a switch from piped engineered systems to practices and systems that use and enhance natural processes (infiltration, evapotranspiration, filtration, retention, reuse) to mimic the site predevelopment hydrology. Known under different names across the globe, the term Sustainable Drainage Systems (SuDS) is used throughout the present thesis to refer to this approach. SuDS currently in use include green roofs, rain gardens, permeable pavements, infiltration basins and daylighting of culverted water bodies (Figure 1); they can be combined with conventional techniques (pipes) and retrofitted into existing drainage systems.

Figure 1. *Rain garden in Philadelphia (left); infiltration basin in Barcelona (right).*

While conventional drainage focuses on stormwater quantity management (rapid collection and conveyance to receiving bodies, without previous treatment in many cases), SuDS place equal emphasis on water quantity, water quality, amenity and biodiversity, the three spheres of the SuDS 'triangle' (Woods-Ballard et al., 2007). In addition, there are other benefits that SuDS can provide (specially the vegetated devices) that are important to consider in a changing climate. Carbon sequestration and storage, urban cooling, flood resilience, human-health and well-being have been incorporated by Charlesworth (2010) into the representation of SuDS, baptizing the new one as the SuDS 'rocket'.

Best practice utilizes a chain of SuDS devices, a 'management train', to mimic natural catchment processes as closely as possible. This prioritizes prevention and control of water at source (i.e. green roofs, pervious pavements, bioretention areas) before considering site or regional controls (i.e. wetlands, ponds) (Woods-Ballard et al., 2007), although this is not always the approach followed in practice (Bastien et al., 2010). In mimicking nature, SuDS can provide 'ecosystem services' such as water resources, flood protection, biodiversity, climatic regulation, recreation, aesthetic inspiration, opportunities for social interaction, stress reduction, environmental education, healthier and more livable cities (Apostolaki et al., 2006; Hamel et al., 2013; Jones and Davis, 2012; Novotny et al., 2010; USEPA, 2008), contributing to the positive integration with, and restoration of, local ecosystems (Pedersen-Zari, 2012). Hence they can help cities transition towards more sustainable environments which are more resilient to changing future conditions (Lundy and Wade, 2011).

Since the philosophy of SuDS is to provide space for surplus water within the urban area, additional resilience to floods and droughts can thus be built automatically into SuDS. The storage gives a measure of protection against flooding through attenuation but it also can provide a source of water for re-use within the city. A further issue is the amount of energy used in the water and drainage sector, and by preventing rainwater from flowing into the drains, there will be less pumping and less treatment to provide water for irrigation and toilet flushing (and less energy wasted on transport and treatment of runoff).

In a scientific and engineering sense, the performance of a SuDS component depends on a range of local conditions such as the construction of the component, soil types and rainfall regime and depends on the local climate. However, to operate in the long term, SuDS must be fully integrated into the city framework and local operational practices and the arrangements for SuDS in a very dense city will be very different from those in a city with less impermeable area and different operational practices.

SuDS have been developed and implemented in many cities in the last 20-30 years (Marsalek and Chocat, 2002; Novotny et al., 2010). However, their wide-scale implementation has been limited (Brown, 2005), with many cities investing heavily in the conventional approach (Wong and Brown, 2009). Insights from different studies on integrated urban water management reveal that barriers are largely socio-institutional rather than technical (Brown and Farrely, 2009;

Rauch et al., 2005) and recommendations call for collaborative planning and multi-stakeholders platforms that involve civil society (Potter et al., 2011; Sanchez-Rodriguez, 2009; van Herk et al., 2011) to deliver a shared vision for the cities of the future (Binney et al., 2010).

Hence, a radical change is required in culture as well as institutions (Pal-Wostl et al., 2008) in order to limit and potentially reverse damage to ecosystems (Pedersen-Zari, 2012). Consideration must be given to the interrelationship of urban stormwater management (USWM) with other sectors (e.g. energy, transport, urban planning, health) (du Plessis, 2012) through a systems thinking, building capacity, building natural and social capital approach, which are the aspirations of regenerative design and development (Cole, 2012).

Sustainable transitions such as those which move towards a regenerative approach to stormwater management have additional complexities to many historical transitions, as they are goal-oriented, addressing persistent and new environmental collective problems, which with achievement do not offer obvious local, immediate, visible and tangible user benefits (Geels, 2011). In addition, scale and context-dependencies of cities present huge challenges to a transition toward sustainability/regeneration (Næss & Vogel, 2012). This makes the participation of public authorities and civil society crucial to a sustainable transition (Elzen et al., 2011).

Governance and planning, in particular the way for stakeholders to collaborate, have been identified as critical to transformative change towards urban sustainability (McCormick et al., 2013), and transition management emerges as an innovative approach for dealing with the complex, uncertain and multi-facetted problems of water management and to bring about the required change of paradigm (Frantzeskaki et al., 2012; Tukker and Butter, 2007; van de Brugge and Rotmans, 2007). However, there is a need for research that puts cities in focus rather than countries or buildings (Cole, 2012; McCormick et al., 2013). Existing conceptual models need to be updated and improved to address the complex reality of urban areas (Ferguson et al., 2013; Sanchez-Rodriguez, 2009), and the question of what tactical and operational transition management looks like needs to be addressed (Loorbach and Rotmans, 2010).

Brown et al. (2013) highlight the importance of institutional work on transition management, suggesting that “more emphasis should be given to this interplay between frontrunners, visions and experiments on the one hand and institutional strategies and structures on the other”. Hence, the formation of new networks, where each member can be a frontrunner in their institution, plays an important role in framing sustainable urban development (Woolthuis et al., 2013).

EU Ministers responsible for Urban Development have highlighted the “need to promote a smarter, more sustainable and socially inclusive urban development in European urban areas, cities and towns”, undertaking “a genuine ‘green, ecological or environmental’ regeneration” that includes ‘re-greening’ the existing city, what offers excellent opportunities for creating new businesses and jobs, better places to live in and more social integration (European Commission, 2010).

In the Spanish framework, some references promote a urban development that reduces runoff and make use of rainwater harvesting techniques as strategies for reducing the effects of floods and droughts (Cabrera and Babiano, 2007; Madrid City Council, 2006; Puertas et al., 2008; Rueda, 2009; Xunta de Galicia, 2009). In terms of water management, recent national legislation (R.D.1290/2012) recognizes the lack of regulation, amongst others, in relation to combined sewer overflows (CSOs), needed to achieve a good ecological status of the water bodies, as required by the EU Water Framework Directive (Directive 2000/60/CE). In terms of urban runoff, it highlights the need to take stormwater out of combined sewers, specifying the use of best available (and affordable) practices and technical knowledge The legislation requires future technical rules to be developed, and it would be desirable that they embody recent European guidelines for water management which promote the use of SuDS (European Commission, 2012). This would be aligned with R.D.233/2013, which opens the door to co-finance urban interventions that fall under the SuDS approach (e.g. the sustainable management of urban runoff and the use of green roofs).

Although SuDS have been implemented in many parts of the globe (Novotny et al., 2010), experience is limited in the Mediterranean region (Castro-Fresno et al., 2013; Chouli et al., 2007; D'Arcy and Perales-Momparler, 2013; Febles et al., 2009; Perales-Momparler and Soto-Fernández, 2013; Perales-Momparler and Valls-Benavides, 2013) in particular characterizing the response of SuDS in the region, with its long dry periods and torrential rain (Terzakis et al., 2008). Hence, there is a need for 'learning by doing' experiments which can demonstrate the effectiveness of this new approach (Barbosa et al., 2012; Binney et al., 2010; Casal-Campos et al., 2012; Lamera et al., 2014; Tukker and Butter, 2007) since, according to Nevens et al. (2013), experiments can be major triggers to take-off and acceleration of transitions (Van der Brugge and Romans, 2007).

Indeed, both government and industry require clear evidence about their benefits and costs, customized for the region of study, to be willing to invest. Furthermore, there is evidence that demonstration sites have facilitated the development of mature understanding of innovative approaches such as integrated urban water management (Mitchell, 2006). Demo sites help in the identification of opportunities and substantial cost savings for local communities that are not apparent when separate strategies are developed for each service (Anderson and Iyaduri, 2003).

With much of the literature focusing on barriers to change, successful case studies are required (Brown et al., 2009) with positive vision and narratives to encourage collective action to solve environmental problems (Smith and Raven, 2012) in the context of enhanced and intelligent governance (Halpin and Escuder, 2015), transitioning towards regenerative urban built environments.

1.2. Objectives

The main objective of this thesis is to develop a methodology, with a conceptual framework, specific method and tools, that allows for the understanding and the characterization of the current situation of a urban stormwater system in a process that guides future actions to move towards the desired regenerative urban built environment concept, with a place-based holistic view.

The above general objective can be subdivided in a series of more specific milestones which are the following:

- Review of the state of the art regarding conceptual frameworks for sustainable/regenerative development, specifically those applied to urban areas.
- Review of the state of the art in regards of existing tools to guide and assess progress on transitions at urban scale.
- Selection of a suitable framework and tools and their adaptation to the city scale, in particular to deal with urban stormwater management, integrating them within the methodology.
- Application and verification of the proposed methodology to a Mediterranean city.

2. PUBLICATIONS

This thesis is a compendium of research papers. It includes three articles published in peer reviewed journals indexed in the Journal Citations Reports (JCR), one sent to one of those journals and two communications published in Congress Proceedings. They are attached as Annexes, and are the following:

I. Papers published in indexed journals (JCR):

1) **S. Perales-Momparler**, I. Andrés-Doménech, J. Andreu Álvarez, I. Escuder-Bueno, I., in press. **A regenerative urban stormwater management methodology: the journey of a Mediterranean city**. Journal of Cleaner Production (**in press**). doi: 10.1016/j.jclepro.2015.02.039. JCR Journal Impact Factor in 2014: 3.844; Q1. **Annex 1**.

2) **S. Perales-Momparler**, C. Hernández-Crespo, F. Vallés-Morán, M. Martín, I. Andrés-Doménech, J. Andreu Álvarez, C. Jefferies, **2014**. **SuDS Efficiency during the Start-Up Period under Mediterranean Climatic Conditions**. Clean-Soil Air Water 2014, 42 (2), 178–186. doi: 10.1002/clen.201300164. JCR Journal Impact Factor in 2014: 1.945; Q2. **Annex 2**.

3) S. M. Charlesworth**, S. Perales-Momparler**, C. Lashford, F. Warwick, **2013**. **The sustainable management of surface water at the building scale: preliminary results of case studies in the UK and Spain**. J. Water Supply Res. T. 62.8, 534-544. doi: 10.2166/aqua.2013.051. JCR Journal Impact Factor in 2014: 0.843; Q3. **Annex 3**.

4) **S. Perales-Momparler**, I. Andrés-Doménech, C. Hernández-Crespo, F. Vallés-Morán, M. Martín, I. Escuder-Bueno, J. Andreu. **The role of monitoring sustainable drainage systems for catalyzing transition towards regenerative urban built environments: a case study in the Valencian region, Spain**. Submitted to Journal of Cleaner Production. JCR Journal Impact Factor in 2014: 3.844; Q1. **Annex 4**.

II. Papers published in Congress Proceedings:

5) P. Millán Romero, B. Nácher-Rodríguez, C. Hernández Crespo, M. Martín, F. J. Vallés Morán, I. Andrés-Doménech, **S. Perales-Momparler**, 2013. **Análisis comparativo de las escorrentías producidas en un pavimento permeable y en una calzada convencional**. Pages 131-138. In: F. J. Vallés-Morán, I. Andrés-Doménech, I. Escuder-Bueno, P. A. López-Jiménez, J. B. Marco Segura (eds), 2013. III Jornadas de Ingeniería del Agua. La protección contra los riesgos hídricos. Vol 2. (ISBN 978-84-267-2071-9). **Annex 5**.

6) **S. Perales-Momparler**, C. Jefferies, E. Periguell-Ortega, P. P. Peris-Garcia, J.L. Munoz-Bonet, **2013**. **Inner-city SUDS retrofitted sites to promote sustainable stormwater management in the Mediterranean region of Valencia: AQUAVAL (Life+ EU Programme)**. NOVATECH 2013, Lyon, France. **Annex 6**.

3. RESULTS AND DISCUSSION

Results of this thesis are presented in the publications that form the Annexes of this document, and summarized in this chapter.

3.1. A regenerative urban stormwater management methodology

Under the well-known slogan 'think global, act local', cities in the 21st century face the enormous challenge of catalyzing, intensifying and accelerating sustainable urban transformations, that can be defined in two dimensions: first, drivers of 'radical' change, such as governance and planning, innovation and competitiveness, and lifestyle and consumption; and, second, 'multi-dimensional' sustainable urban structures, which include resource management and climate mitigation and adaptation, transport and accessibility, buildings, and the spatial environment and public space (McCormick et al., 2013).

Without losing this holistic view, the methodology presented herein (**Annex 1**) places the focus on 'resource management and climate mitigation and adaptation', in particular in USWM, proposing processes that can bring about the required change, shaped by the place-based approach of the regenerative sustainability paradigm (Mang and Reed, 2012).

It is important to integrate strategic resource management with urban spatial planning (Agudelo-Vera et al., 2011), which for stormwater management includes adapting urban layout to existing water corridors and patterns (Perales et al., 2011). Moreover, promotion of character in townscape and landscape "rooted in the context and its social-ecological narratives" (du Plessis, 2012) must be embraced by the different agencies working in the region (Biddulph, 2011). Hence, the author proposes a new representation for the regenerative approach to stormwater management, in the line of the previous representations by Woods-Ballard et al. (2007) and Charlesworth (2010): the SuDS 'landed rocket' (Figure 2). In doing so, the author incorporates the connection to the place, in a way that people "are vitalized and become intrinsically motivated to care for it" as a result, bringing about "the transformation of our cities into places that are life enhancing and regenerative" (Mang, 2009).

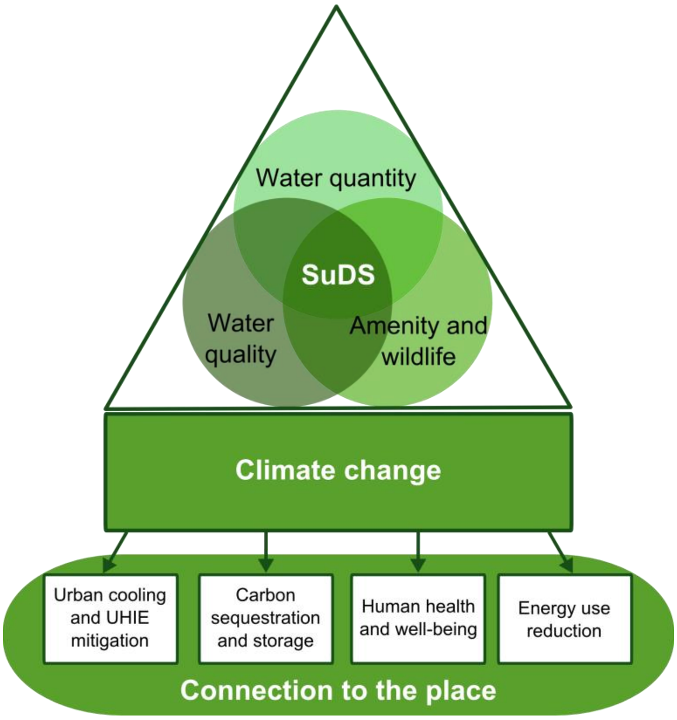


Figure 2. *The SuDS landed rocket (after Woods-Ballard et al. (2007) and Charlesworth (2010)). Annex 1.*

From the above, the author understands that, if properly designed and integrated, SuDS could comply with the three insights that form the basis of the regenerative paradigm (du Plessis, 2012): a) necessity to follow a development approach based on how nature works; b) interpretation of the world as an ever-changing, impermanent and inherently unpredictable set of processes; and, c) the notion that humans participate in the production, transformation and evolution of the ecosystem in which they find themselves.

The desired transformation of cities, from the lens of USWM while understanding the breath of the whole system, is depicted conceptually in Figure 3. It builds on work by Reed (2007) and incorporates four representations of stormwater practices nested into the SuDS 'landed rocket' (Figure 2). They relate to the nested levels of progression towards a regenerative design: while green design is primarily directed at doing 'less harm', sustainability is a 'neutral' state that provides the necessary base condition to permit regenerative capabilities to evolve (Cole, 2012). Regeneration is about engaging the "entirety of what makes a place healthy", entering an 'evolutionary spiral' in which three essential aspects catalyze the design process: "understanding the master pattern of place; translating the patterns into design guidelines and conceptual design; and, ongoing feedback – a conscious process of learning and participation through action, reflection and dialogue" (Reed, 2007).

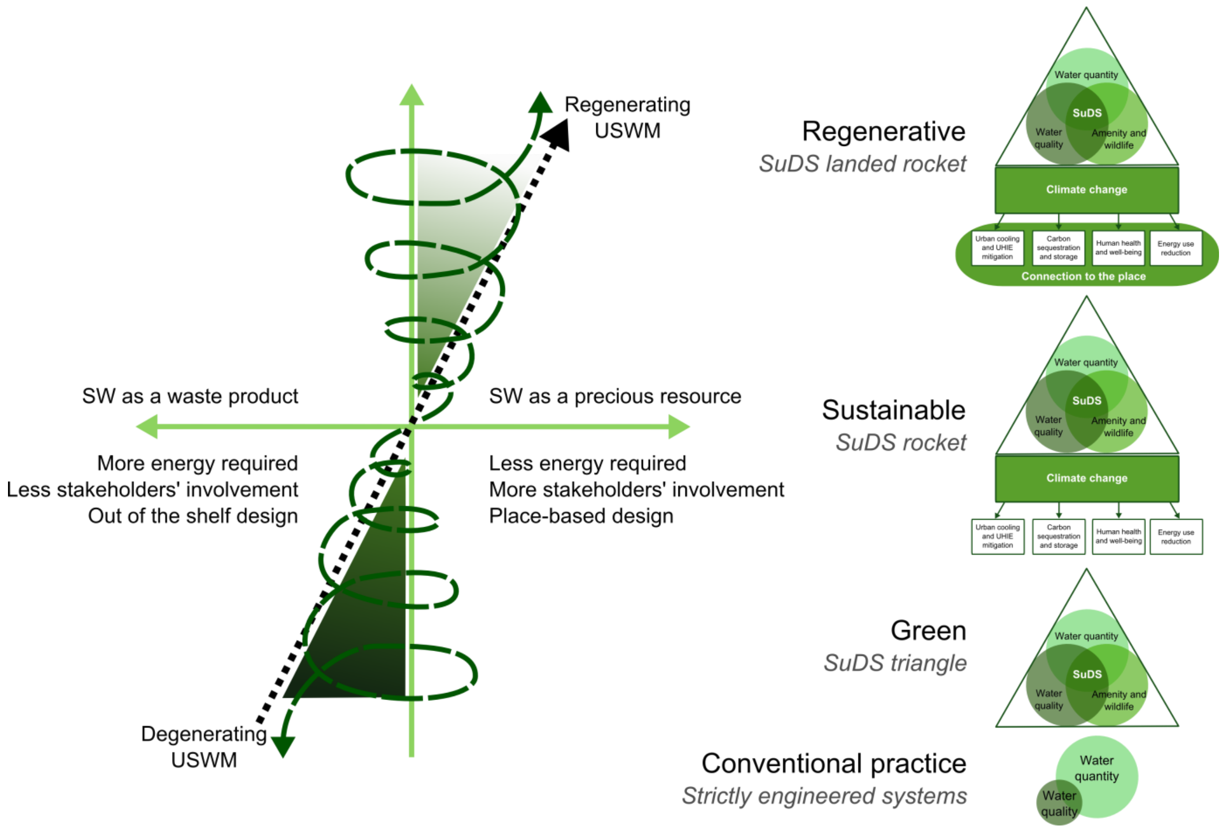


Figure 3. *Trajectory of Environmentally Responsible Stormwater Management (after Reed (2007)). Annex 1.*

The methodology proposed in this thesis for approaching the concept of regenerative urban built environment focuses on municipal infrastructure systems or sub-systems (in this case USWM) with a holistic view. This is a step forward from the more common situation where it is applied to buildings or particular developments (Cole, 2012). It is intended to be used at a local level, with a place-based approach that integrates and frames planetary issues (such as energy and global warming) "in manageable, meaningful and, literally, grounded context" (Reed, 2007).

This methodology (Figure 4) is based on that proposed by Mang and Reed (2012), adapted to deal with USWM, with the aim of advancing the SuDS 'landed rocket' within the vision of a regenerative built environment. It includes the framework previously described and a new method that incorporates tools previously proposed by other authors (but not linked), using them as guidance and to assess the progress achieved. The methodology is structured in 3 tiers: Tier 1 presents the thinking behind tiers 2 and 3, the desired paradigm: a regenerative built environment; Tier 2 depictures the theoretical framework (Figure 3), that enables comprehending and visioning of the complex systems analyzed, USWM in this case; and, Tier 3 provides practical method and tools for advancing in the desired direction, "engaging the people who will need to sustain and develop the process over time" (Mang and Reed, 2012).

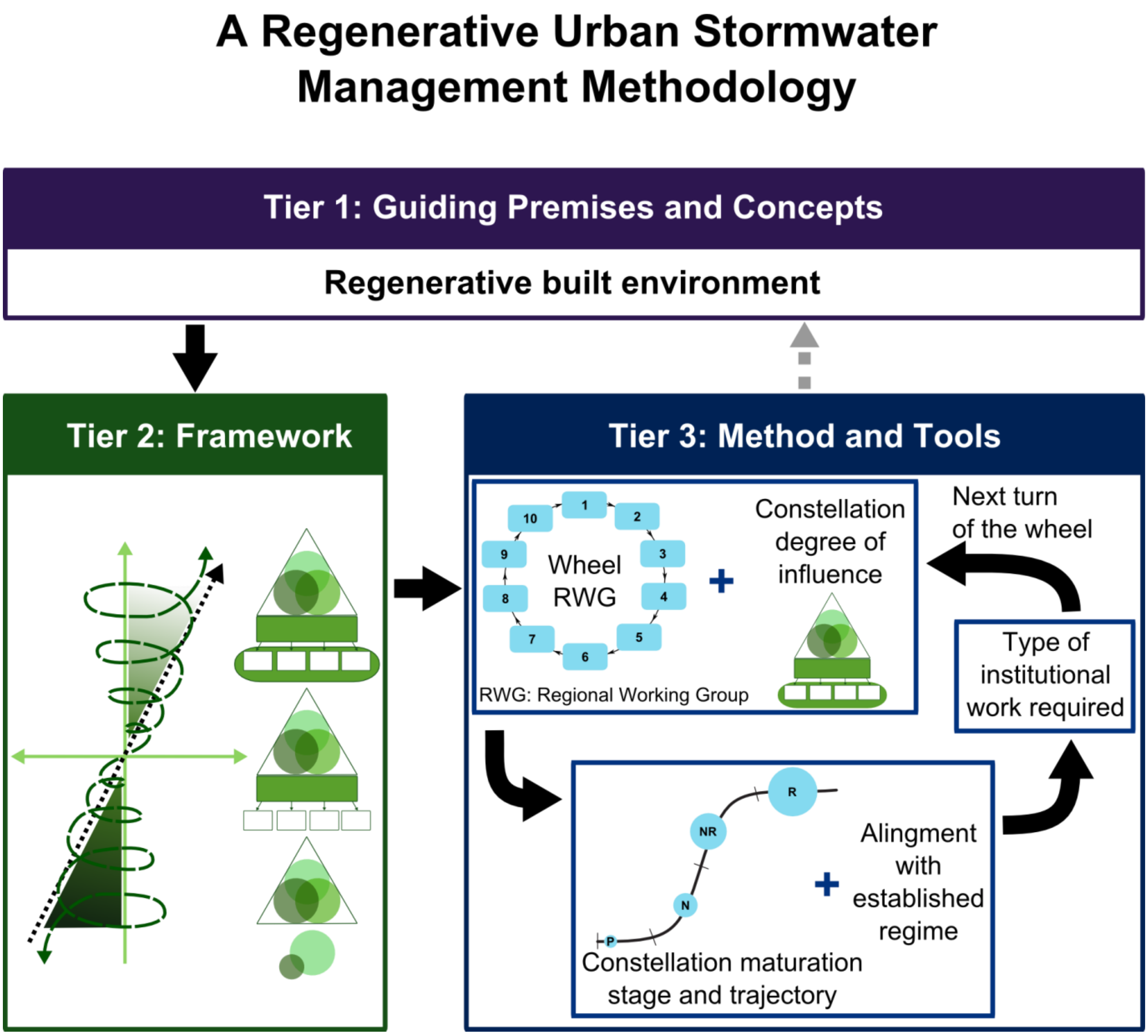


Figure 4. *A regenerative urban stormwater management methodology. Solid arrows show the route between tiers and link the cyclical steps within Tier 3. The dashed arrow represents the possibility to refine concepts during the process. Annex 1.*

The method proposed in tier 3 incorporates as a first tool the 'Sustainable Transition Management Cycle' that lies at the core of the so called 'SWITCH Transition Framework' (Duffy and Jefferies, 2011), intended for decision makers at national and local scales, being of great assistance also to urban water practitioners and decision makers in the urban water sector. SWITCH (Sustainable Water Improves Tomorrow's Cities Health) was an EU funded action research program which overall goal was to catalyze change towards more sustainable urban water management in the 'City of the Future' (van der Steen and Howe, 2009).

The 'Sustainable Transition Management Cycle' consists of ten activities that take place at three management levels (Figure 5): Strategic, where long-term ambitions and goals are formulated, requiring strategic thinkers that are open to change and reflection; Tactical, aiming to gain societal support and attention for sustainability objectives and intermediary goals, by developing networks and coalitions that can identify and overcome structural barriers; and, Operational, based on short-term experimenting with innovations that have potential to materialize the strategic vision, informing actors about specific barriers in different environments (Loorbach, 2007). These levels do not represent a hierarchy and although different types of actors participate at each level, a diverse set of competencies and skills are required across all levels (Jefferies and Duffy, 2011).

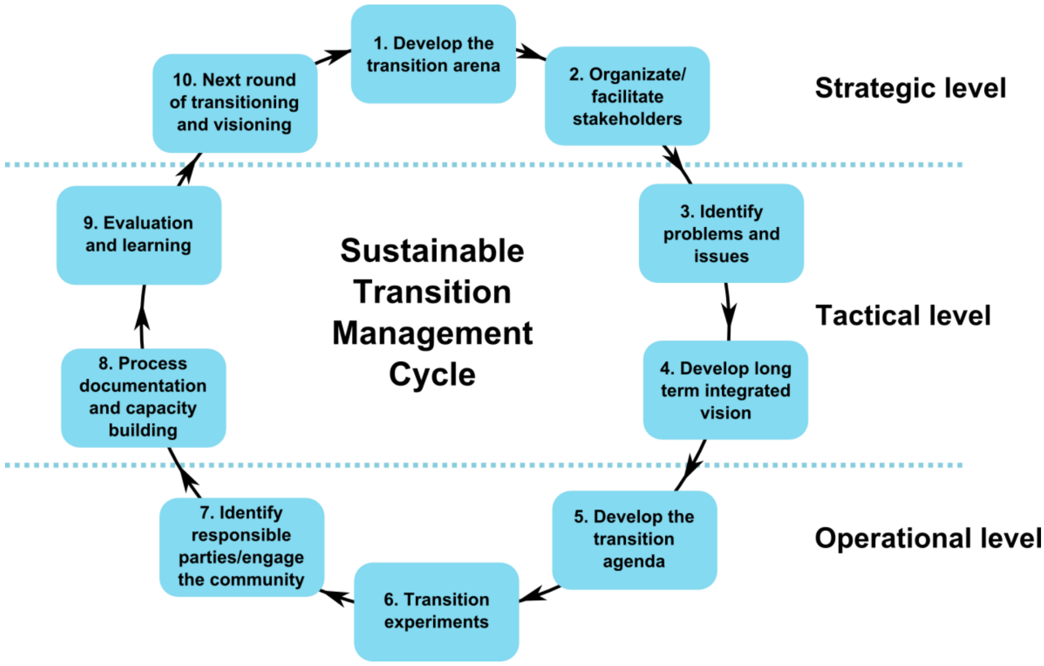


Figure 5. *The sustainable transition management cycle (Adapted from Duffy and Jefferies (2011)). Annex 1.*

This cycle is driven by the SWITCH so called 'Learning Alliance', a stakeholders group made up from government bodies, user groups and research institutions that bring new ideas, techniques and innovations into a city, and has strong powers of influence in commissioning and nurturing projects that demonstrate the implications of the transition being promoted in the city. Throughout this thesis, the Sustainable Transition Management Cycle will be referred to as the 'wheel', whereas the 'Learning Alliance' will be the Regional Working Group (RWG). A front-runner capable of effectively engaging relevant stakeholders in the region is crucial for the creation and coordination of a RWG that endures over time.

The author of this thesis proposes to use the 'wheel' to guide the cities' 'regenerating trajectory'. It has been selected for its city-water approach that builds on transition theory (the multi-phase concept, the multi-level perspective, transition management and strategic niche management). 'Steering the wheel' should not be viewed as a way to control societal changes; by contrast it is a method for the exploration in a reflexive manner of a new city governance approach (Nevens et al., 2013).

In addition to being used as a guide, it is a valuable tool to classify the activities carried out in a particular city or region (the case study), so an assessment can be made of the strengths developed over time as a way to 'measure' the progress achieved along the transition pathway. The numbering of the activities does not imply any implementation order, as strengths can be developed in any sequence. However, numbers have been added in Figure 5 to facilitate the consequent analysis.

Although it is common to represent transitions at the system scale (Geels and Schot, 2007), this thesis place the focus for the transition analysis on one part of the system (Loorbach and Rotmans, 2010), i.e., USWM versus urban water management. Furthermore, conceptualizing the SuDS 'landed rocket' as an individual 'constellation' within the USWM system, it is possible to identify what type it is according to its 'degree of influencing' ('share of power') of the overall system (de Haan and Rotmans, 2011): regimes are the most powerful, niche-regimes have moderate power, niches have low power and pre-niches have no power. The analysis carried out through the wheel activities can determine what the degree of influencing of the SuDS 'landed rocket' is in the case study.

The method proposes, based on Ferguson et al. (in press), to use this classification (in terms of its 'degree of influencing') to identify the stage of maturation of this constellation (the SuDS 'landed rocket') over time, using the multi-phase S-curve (Rotmans et al., 2001) and its four stages of a transition: pre-development, take-off, acceleration and stabilization. Consequently, when identifying the maturation stage of the constellation of study and its alignment with the established regime, work by Ferguson et al. (in press) provides some light on the type of institutional work required to support the innovation maturation (Figure 6).

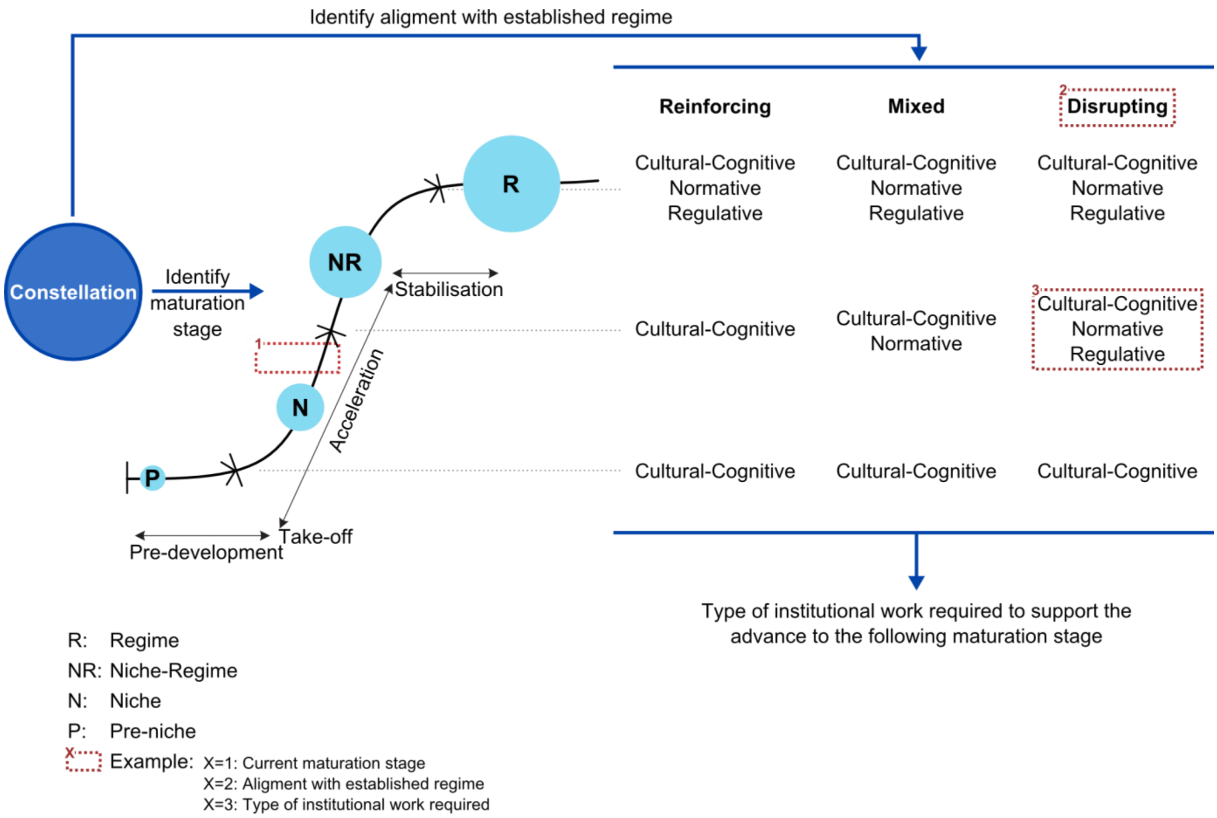


Figure 6. *Identification of the type of institutional work required for supporting key maturity stages (Adapted from Ferguson et al. (in press)). Annex 1.*

To complete the analysis, and as part of identifying the work required and its viability, the thesis proposes to use the classification of 'institutional work' by Ferguson et al. (in press) to present enablers and barriers found in the case study, and compare them with the main type of barriers found by Brown and Farrely (2009).

In summary, within Tier 3, the first step is to examine the strengths already developed within the wheel activities (Figure 5) and the relative degree of influence of the SuDS 'landed rocket' within the current USWM system. This analysis allows depicting the stage within the constellation maturation curve and the alignment with the established regime at present. Consequently, the type of institutional work required for supporting key maturity stages is identified (Figure 6), which can be linked to particular activities programmed to develop strengths within the wheel. After a period of time, the analysis will be conducted again, assessing the progress achieved and planning the following turn of the wheel.

Strengths developed within each turn of the wheel can be color coded. The size of the balls that represent the constellation stages are linked to their 'degree of influencing' of the overall system (i.e. the most powerful, regime, is represented with the biggest size ball). Hence, the wheel, together with the picture of the constellation maturation stage and trajectory, provide a visual and effective set of indicators to track progress and plan for future actions.

In the case study presented in section 3.2, strengths developed are identified by naming actions undertaken within each activity, and expert judgment determines whether the strength has been developed lightly or strongly, as well as determining the SuDS 'landed rocket' maturation stages and trajectory. The alignment with the established regime is conducted by examining enablers and obstacles for each type of institutional work presented in Ferguson et al. (in press). Future research could lead to a parametric analysis being proposed for this examination. Furthermore, while we focus on the institutional work required depending on the constellation's alignment with the established regime, the methodology itself leaves the door open to embrace in the future additional tools and methods.

A theoretical application of this framework (Figure 4) would start in Tier 1 by defining which is the desired paradigm and continue with depicting the framework to journey towards it, Tier 2. Then the proposed method and tools presented in Tier 3 would be followed in a cyclical way, starting from scratch. However, real cities might have travelled part of the journey without framing it within a conceptual model and formal definition of Tiers 1 and 2 could happen on the way. This is what happened in Benaguasil, the case study presented in section 3.2. In addition, progress within Tier 3 could suggest refinements of concept in Tiers 1 and 2 (e.g. adding a new parameter along the x axis in Figure 3).

3.2. Urban stormwater management in Benaguasil: the journey

The methodology presented in section 3.1. has been applied to the journey of Benaguasil, a Mediterranean city, towards a regenerative built environment.

A longitudinal narrative of the case study research is presented in Perales-Momparler et al. (in press), in **Annex 1**. The focus of the narrative and the consequent analysis is in the interplay between frontrunners and the institutions. Perales-Momparler et al. (2013), in **Annex 6**, describes the different activities that took place in the frame of the first EU funded project that facilitated the uptake of the SuDS approach in Benaguasil (www.aquavalproject.eu). More technical aspects of the experiments (activity 6 of the wheel), consisting of the construction and monitoring of SuDS showcases in the Valencian region, can be found in Perales-Momparler et al. (2014), in **Annex 2**; Charlesworth et al. (2013), in **Annex 3**; Perales-Momparler et al. (with editor), in **Annex 4**; and Millán-Romero et al. (2013) in **Annex 5**. The principal aspects are summarized in this section.

Located 20 km inland from the city of Valencia (in the western Mediterranean on the Spanish coast) and currently counting with over 11 000 inhabitants, Benaguasil has appreciated the value of water from ancient times, being essential for its agricultural based economy (Grau, 1995).

With a mild and semi-arid climate, Benaguasil has an average annual rainfall of 432 mm, with very strong seasonality. As many Mediterranean cities, it experiences very high peak rainfall intensities that concentrate in short periods of time, which together with city characteristics such as high population density (4 750 hab/km^2 in Benaguasil) and large impermeability, difficult urban stormwater management.

Nowadays the town faces three major problems in terms of USWM: frequent pluvial flooding and backup flows from overloaded combined sewers into dwellings, pollution of water courses from CSOs and high energy consumption. Believing that the solution could not come only from increasing the capacity of conveyance and treatment facilities, the Municipality of Benaguasil started to think 'out of the box', understanding that a more natural approach and raking up traditional practices might be needed.

Since 2008, Municipality of Benaguasil has been involved in several research projects at European level, looking for an alternative regenerative approach to traditional stormwater practice. AQUAVAL (www.aquavalproject.eu) and E^{2}STORMED (www.e2stormed.eu) are the cornerstone projects, while the involvement in the SUFRI (www.sufri.tugraz.at) project and the PiP program (www.climate-kic.org/pioneers) built up on the efforts to achieve the desired transition.

In 2008, the author of this thesis envisaged the opportunity and worked towards the formation of a consortium in the Valencian region to apply for European funding, in order to promote this innovative approach which was little understood in the country at that moment (Castro-Fresno et al., 2013; Perales and Andrés, 2008). The partnership comprised two municipalities in the region (Xàtiva and Benaguasil), the author's consultancy firm, a UK University as an international expert on SuDS and a regional public entity that deals with EU relationships in the role of 'communication partner'. It counted with Diputació de València (county council) as co-financer for the construction of the proposed pilot SuDS sites. The proposal was approved for European Regional Development Fund (ERDF) co-financing and the AQUAVAL project started in January 2010.

The guiding principle of AQUAVAL was to make the best use of municipalities' landscape and morphology in order to integrate water infrastructure using SuDS, adding social and environmental values. The project comprised the construction and monitoring of pilot SuDS as an important step towards the required change of paradigm. The scope of the project also included production of sustainable urban stormwater management plans and policies with the aim of making drainage infrastructure versatile and able to cope with the effects of climate change.

Three inner-city areas were selected and retrofitted in Benaguasil, and three in Xàtiva, to accommodate runoff from nearby surfaces, decreasing the flow rate and volume of stormwater that enters the combined sewer networks (frequently causing CSOs) or freely flows through the streets (occasionally flooding dwellings). The author of this thesis actively participated on the selection of the sites and provided guidance during the detail design and construction phases of these showcases. Figure 7 depictures the SuDS that were developed/retrofitted and monitored for a year, which main characteristics are presented in Table 1.

Figure 7. *Showcase sites after SuDS development/retrofitting in Xàtiva (upper row) and Benaguasil (lower row). Annex 4.*

Local stakeholders gained knowledge on this innovative stormwater management approach during the selection process, which in Benaguasil led them to propose changing the projected impermeable car park of the new public indoor swimming pool for a permeable one (Figure 8) within the same budget. This car park was the first pilot constructed in Benaguasil using the new approach (increasing the number of pilots in Benaguasil to four). The seven SuDS schemes were equipped with suitable instrumentation, and monitored for a year both in terms of runoff quantity and quality.

Site Code: location	Type of SuDS	Main function	Criteria for site selection	Quantity monitored variable	Quality Monitored variables
X1: Xàtiva Sports City	Infiltration basin	Runoff reduction	Drainage required and public space available	Discharge from the basin	Inflow from recreation area and the road; outflow to sewer
X2: Xàtiva North Ring Road	Roadside swale functioning as a longitudinal infiltration basin	Runoff reduction and quality improvement	Drainage required and public space available	Discharge from the swale	Inflow from roads; outflow to sewer
X3:Gonzalbes Vera public school in Xàtiva	Green Roof	Runoff reduction and building insulation	Educational opportunity; comparison on runoff discharged from the green roof and from the conventional roof	Runoff from the green roof and from the conventional roof	Atmospheric deposition; outflow from green roof and from the conventional roof
B1: Costa Ermita park in Benaguasil	Detention-infiltration basins	Sediments detention and runoff reduction	Public space available in an elevated town area	Discharge from the basin	Inflow from roads; outflow to sewer
B2: Benaguasil Youth Center	Underground-concrete rainwater harvesting tank	Rainwater harvesting	Educational opportunity and revival of a lost ancient practice	Volume stored in the tank	Atmospheric deposition; harvesting tank
B3: Les Eres industrial park in Benaguasil	Infiltration basin	Runoff reduction	Showcase for future expansion of industrial area and public space available	Discharge from the basin	Inflow from industrial warehouse; outflow to sewer
B4: Public indoor swimming pool car park	Permeable paving	Runoff reduction and water quality improvement	Funds available for a conventional car park construction	Discharge from the car park and from a gully in a nearby conventional access road	Outflow from the car park and from a gully in a nearby conventional access road

Table 1. *Summary description of showcase sites.*

Figure 8. *Openning of the public indoor swimming pool permeable car park. Benaguasil (Valencia), June 2011. Annex 6.*

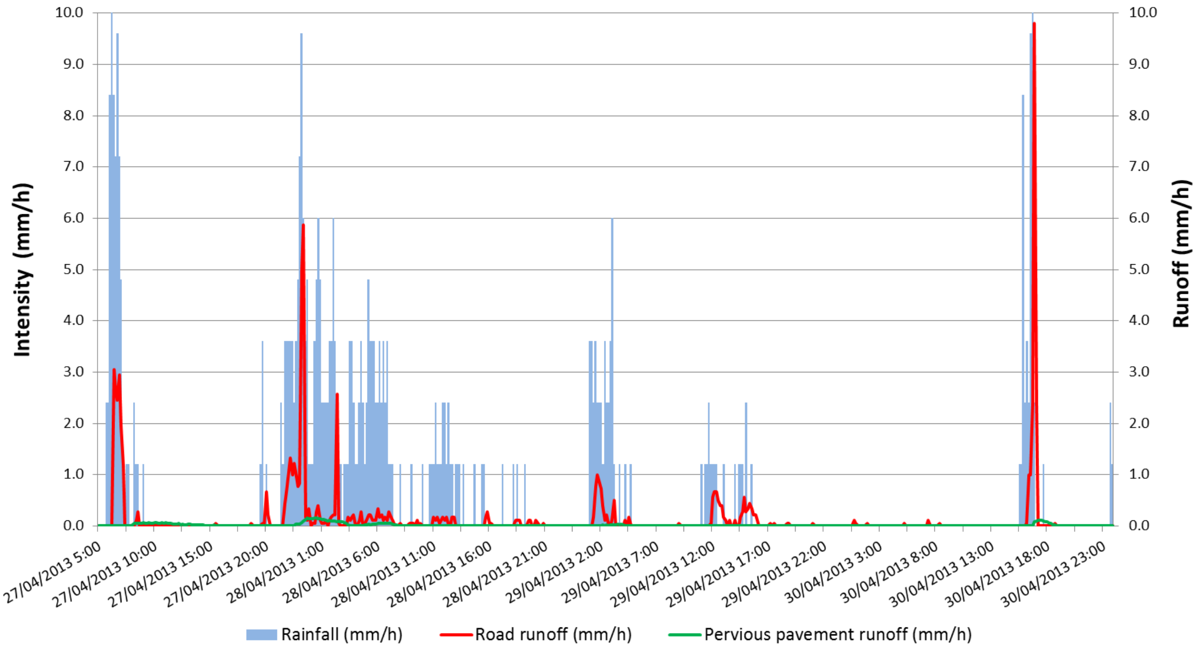


Figure 9. *Benaguasil public indoor swimming pool permeable car park performance during rainfall event 14 (April 2013).*

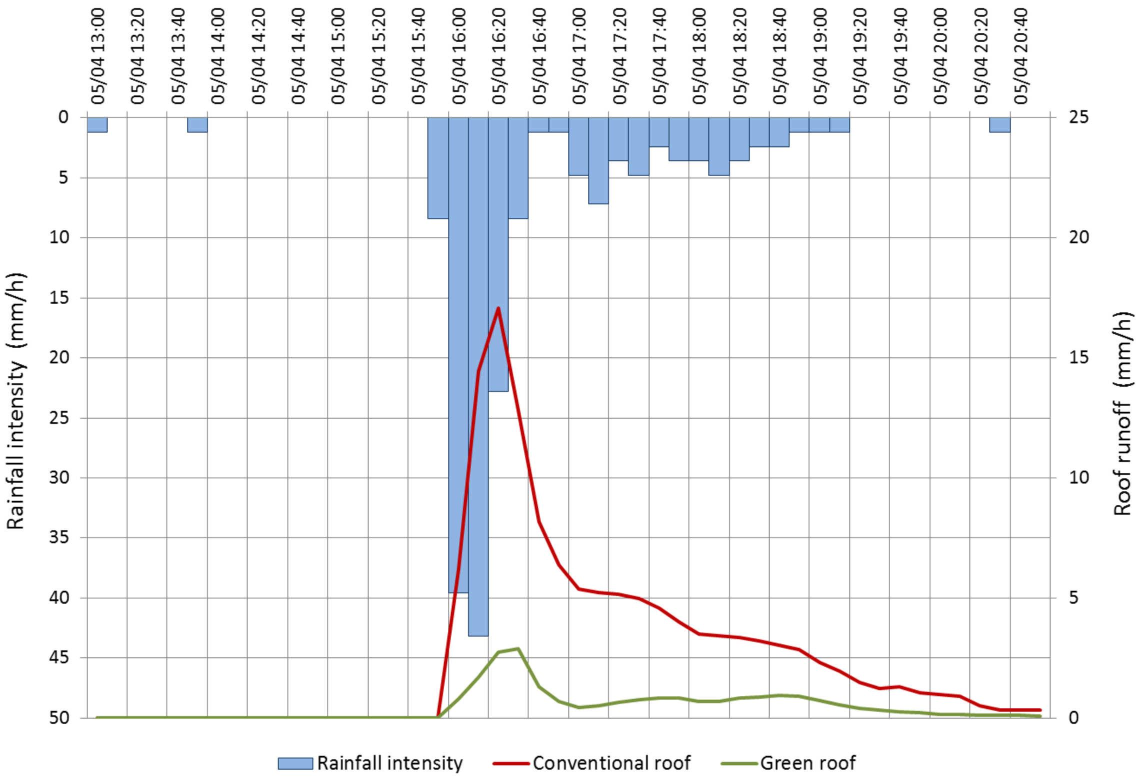


Figure 10. *Comparison between the green roof and the conventional roof runoff in Xàtiva during rainfall event 13 (5th April 2013). Annex 4.*

Data from the monitoring campaign undertook during the AQUAVAL project (October 2012 to September 2013) show that the pilots SuDS have good hydraulic performance under typical Mediterranean climate (Figures 9 and 10). One of the most important barriers for their implementation in this area was the lack of local experience and the uncertainty on their performance. The results show that SuDS are also suitable and reliable under a climate with small rainfall totals but with torrential events. Overall the volumetric hydraulic performances achieved were quite high with retention very close to 100% except for the green roof. Peak flow control is also important and rainwater harvesting and reuse has also been shown as plausible with the pilots.

From the standpoint of water quality, the study has allowed the degree of pollution to be distinguished between three types of urban surface: roofs, gardens and roadways. The latter generate much higher concentrations of organic matter (up to 1 600 mg·L^{-1} of COD) and suspended solids (up to 3 083 mg·L^{-1} SST), reflecting the influence of traffic. Results show that the grass swales and infiltration basins improve water quality before it is discharged to the sewer system (maximum COD discharged of 478 mg·L^{-1}) although this improvement is irregular depending on the hydraulic retention time. This quality improvement is sufficient to meet discharge municipal ordinances (e.g. COD lower than 1 000 mg·L^{-1}, typical value of discharge requirement) and to ensure the proper functioning of the waste water treatment plant (WWTP), thus minimizing impacts on the receiving waterbody. Consequently, an important part of the contaminated load is retained and naturally treated by the SuDS infrastructures, so polluted loads discharged to the sewer system or any receiving water body are significantly reduced. However, the efficiency of these systems should not be measured only in terms of the reduction in pollutant concentration but also in the reduction of total load spilled. Data gathered from site X3 is a good example of this: although runoff from the vegetated part (green roof) has higher pollutant concentrations than its non-vegetated counterpart, less runoff volume is discharged, resulting in less total pollution leaving the site.

Lessons learned through the construction, monitoring, operation and maintenance of the showcase sites will form the basis for future developments in the process of the paradigm shift leading to a broader uptake of SuDS in Spain. As a very practical example, monitoring results from the green roof retrofitted in Xàtiva guided the design and operation of a green roof retrofitted later in Benaguasil as part of the E^2STORMED European project. For instance, in order to minimize the leaching of nutrients, the substrate composition used in this second green roof was different: with soil of lower nutrient content and the use of controlled release fertilizers. In terms of operation, irrigation is now controlled by the soil moisture and vegetation water demand instead of being periodically activated. The Benaguasil green roof is currently being monitored for its hydrology coupled with energy consumption observations (Alfonso et al., 2015).

Being the SuDS demonstration sites the core of the AQUAVAL project, additional groups of activities were undertaken, including the creation and coordination of a RWG involving in the project actors from across the region in the water sector, public and private (with a high representation of design professions, e.g. architects and engineers, and the economic sector). The status of the 'communication partner', a regional public entity that deals with EU relationships, was essential in the successful response of the actors to the call to form the RWG, not only for the number of attendees, but for the political and managerial representativeness, which attracted the attention of the media, with the opening ceremony of the public indoor swimming pool permeable car park (2nd RWG meeting) being broadcasted by the regional TV at premium midday news program. Despite the interest roused, this RWG only met twice at the first part of the project due to the fact that the 'communication partner' had to abandon the project in December 2011 and was not replaced.

In April 2012, the author of this thesis, the Municipality of Benaguasil and members of the Universitat Politècnica de València envisaged that boosting this regenerative sustainability approach within the town and up-scaling and influencing standard practices would "require a programmatic rather than a single project-based approach" (McCormick et al., 2013). With this idea, and the will to extend this approach to other Mediterranean regions and link water management to other sectors such as energy, the E^2STORMED project was born, approved for co-financing from the ERDF, and started in January 2013. It addresses the challenge of improving energy efficiency in the urban water cycle in Mediterranean cities by the use of innovative stormwater management systems (Escuder-Bueno et al., 2013). With 6 operational partners (local authorities) and two academic ones, project activities evolve around the sustainable transition management cycle.

The application of the methodology proposed in this thesis to Benaguasil is an example of how it can be used even when the journey started (AQUAVAL project) prior to explicitly formalizing the desired paradigm and the visioning for USWM (Tiers 1 and 2). The author identifies that one cycle of Tier 3 had occurred before Tiers 1 and 2 where defined, with main focus was the construction and monitoring of SuDS showcases (Activity 6 of the wheel). Afterwards, in Tier 3 a second turn takes place (within E^2STORMED project), with more envisaged to follow.

In the second turn, the most significant effort was at the beginning of the E^2STORMED project in selecting the actors to form part of the RWG and meet with them (activities 1 and 2 of the wheel). The author of the thesis was deeply involved in the selection process, as a SuDS specialist assistant to Benaguasil City Council. The objective was to form a reasonable size group that allowed for a productive dialog, formed by key local and regional entities in urban planning, water and energy sectors, represented by a mixture of political, technical and managerial background actors.

In the case of the E^2STORMED, experiment activities (activity 6 of the wheel) consisted of the selection of two areas within the city (an urban area that could be retrofitted and a future urban expansion) and the application of the Decision Support Tool developed by universities (Escuder-Bueno et al., 2013) to compare two different drainage scenarios in each area (one with conventional drainage infrastructure and one with the SuDS regenerative approach). In addition, a green roof has been retrofitted in a public building in Benaguasil, and its effects in energetic and hydraulic terms are being monitored (Alfonso et al., 2015).

According to Nevens et al. (2013), "applying transition management in a city policy environment is a transition in itself", and that it is the main differential factor of the two turns of the wheel that the author has identified in Benaguasil transition to date. A summary description of Benaguasil journey towards a regenerative USWM is depictured in Figure 11 and summarized as follows:

- *First turn of the wheel*: relating the potential benefits of SuDS (water quantity, water quality, amenity, biodiversity, link to the place) with impacts of landscape pressure (flooding, contamination of water courses, impacts of climate change) has allowed progression form pre-niche to niche, carrying mainly cultural-cognitive institutional work (e.g. dissemination of scientific knowledge; technology testing with practical experience on design and maintenance; gathering of empirical data from experiments that confirms SuDS benefits at the same time that provides learning experience for future applications). In addition, some preliminary (not completed) work was undertaken in the normative (e.g. informal networks; draft Benaguasil Sustainable USWM Plan) and regulative (e.g. draft local ordinances for USWM) types of institutional work.

- *Second turn of the wheel*: progress has been achieved by reinforcing the cultural-cognitive type of work (e.g. developing and testing the tool for decision makers; dissemination of pilot SuDS monitoring results to a broader audience, including a regional conference for local councils and a national one for professionals and politicians) while focusing on normative work (e.g. bringing together key regional actors that, with a holistic view, shear visions and concerns, and work together to build a strategic program, with coordinated and co-supported actions, towards the achievement of common goals), something that we consider essential for the regulative mechanisms (e.g. municipal USWM ordinance) to be successful.
- *Third turn of the wheel*: the author thinks that further institutional work of all three types is required to mature the SuDS innovation towards a regenerative urban built environment. In particular, dissemination of results from the newly-installed green roof (cultural-cognitive), the commitment of regional institutions to implement the activities included in the Benaguasil Sustainable USWM Plan and the regular use of the Decision Support Tool (normative), and the approval of the municipal USWM ordinance (regulative), are envisaged to be key steps in the next turn of the wheel.

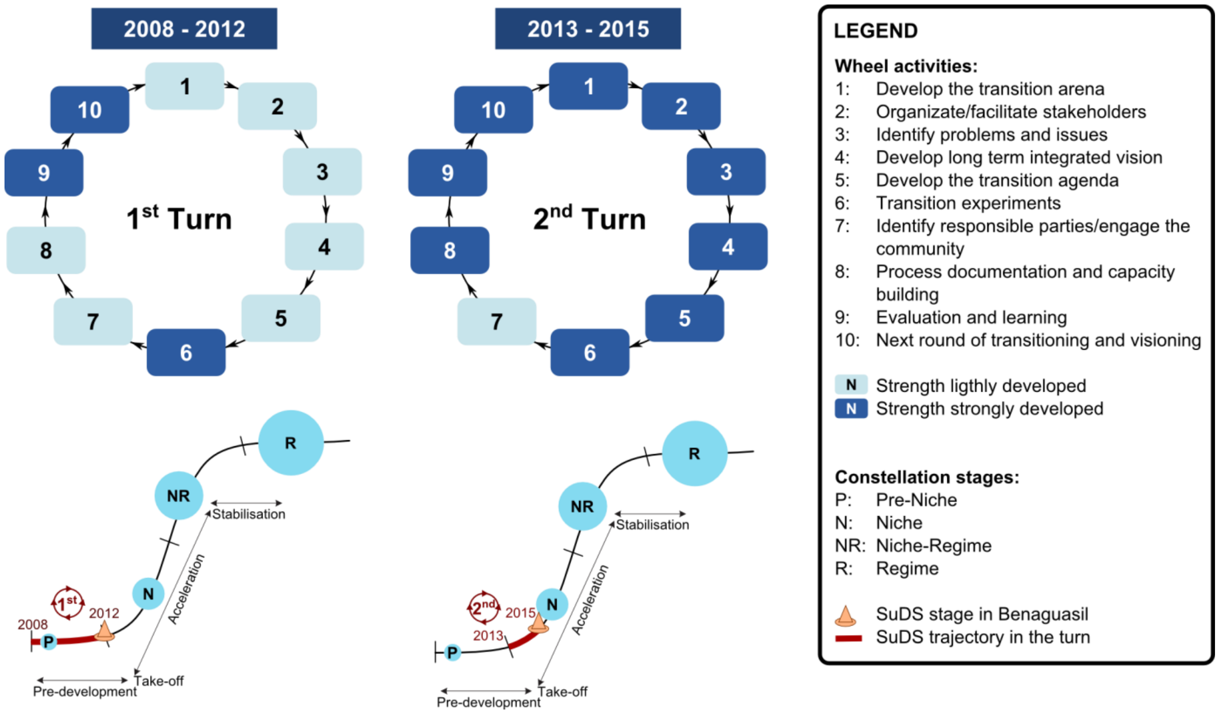


Figure 11. *Set of indicators: identification of the strengths developed (upper part) and SuDS maturation stage and trajectory (lower part) of Benaguasil journey towards a regenerative USWM. Annex 1.*

Whereas in the first turn the author considers that SuDS (an innovative approach with no influence in USWM practices at the beginning of the process) attained the niche stage in Benaguasil, progression on the acceleration section of the maturation curve is slow despite the application of transition management. This was predictable by looking at the steepness with which transition scholars have pictured this transition phase over the years.

Analyzing the barriers and enablers that characterize the transition towards a regenerative USWM in Benaguasil, the SuDS approach can be identified as 'disrupting' the established regime at the three institution types: cultural-cognitive, normative and regulative (i.e., need for new technical knowledge about SuDS, need to integrate ecologists, urban planners, landscape architects, etc. in communities of practices and need for private landowners to engage in providing source stormwater management).

Hence, supporting the SuDS approach maturation from niche to niche-regime will require further actions in all institutional work types (cultural-cognitive, normative and regulative) according to the hypotheses of Ferguson et al. (in press), which are aligned with the Benaguasil experience to date.

3.3. The role of SuDS construction and monitoring as transition catalyzers

Regional Working Group members (in the frame of E^2STORMED project) highlighted the importance of demonstration projects as catalyzers of the transition, in particular when monitoring results are presented in an understandable way for decision makers (i.e. Figures 9 and 10). The AQUAVAL showcase sites have influenced not only local practice, but more important, the support for SuDS in recent regional legislation which dictates that the use of SuDS must be encouraged in all municipalities of the Valencian region (Resolution of 31st October 2013). In this piece of legislation, the Valencian Regional Government presents Benaguasil and Xàtiva showcases as a model to be followed.

It is worth mentioning that Benaguasil projects activities are being echoed by RWG members using their own channels. As an example, the Valencia City Council (Diputación de Valencia), a member of the Regional Working Group, actively disseminates the E^2STORMED project events and outcomes using the "Valencian municipalities towards sustainability network" website (i.e. http://www.dival.es/xarcia/content/sistemas-de-drenaje-sostenible-en-benaguasil-proyecto-europeo-e2stormed).

AQUAVAL has been selected as an example of good practice at European level (Progress Consulting S.r.l. and Living Prospects Ltd., 2011) and nominated as finalist for the Novatech Awards, in the "City or catchment scale strategies" category (www.novatech.graie.org). Achievements at regional and international levels are effective empowerment tools and fuel frontrunners expectations.

In addition, in order to survey the importance given by stakeholders to demonstration activities, a questionnaire was distributed amongst participants on a national workshop on sustainable urban drainage held in Valencia in April 2015 within the framework of the E^2STORMED project. For this survey 6 questions were analyzed: two related to stakeholders' classification (age group and professional affiliation), three to provide their agreement level (completely agree, agree, neutral, disagree and completely disagree) on the importance of demonstration activities (pilot construction, water quantity monitoring and water quality monitoring), and one to choose the single most important activity amongst the latter. For this last question, two additional choices were added: the possibility to have a decision making tool available or none of the above. Questionnaires were distributed electronically few days after the workshop to the 79 attendees.

The questionnaire responses demonstrate the relevance of showcases. A high response was achieved (44%), with respondents belonging to 10 professional affiliations (23% local government professional; 20% consultant; 20% researcher/academic; 14% water utility; 3% regional government professional; 3% national government professional, 3% tradesman; 3% manufacturer; 3% student; 8% others) and from all age group categories (3% 18-24; 17% 25-34; 46% 35-44; 29% 45-54; 6% 55-64).

Responders highly agreed on the importance of demonstration activities. When asked about how much they agreed on the importance of constructing demonstration sites, 89% completely agreed and 9 % agreed. This positivism was repeated, although not as forcefully when asked about the importance of water quantity and quality monitoring activities. In both cases, 66% completely agreed and 31% agreed. When asked to choose the most important demonstration activity, 57% opted for pilot construction, 11% quantity monitoring and 9 % quality monitoring.

At this point it is worth recalling that SuDS provide collective benefits (flood protection, water quality, landscaping, etc.), require collective efforts and challenge the traditional means of stormwater governance, all this making the interaction of stakeholders fundamental.

In other words, poor interaction between stakeholders is incompatible with such enhanced or smarter governance which is by itself also a form of innovation in addition to the innovation brought by means of new constructions and technologies. The way stakeholders have been engaged and how their understanding of the showcase sites as transition catalyzers was assessed, smooths the difficulties that innovation faces in being presented, understood, and endorsed by professionals and decision-makers.

The result is that SuDS are now perceived as a realistic storm water management alternative for both retrofitting and new urban developments in the Valencian region.

4. CONCLUSIONS

4.1. Final remarks

This thesis presents an innovative methodology for approaching the regenerative urban built environment concept focusing on municipal infrastructure systems or sub-systems (in this case stormwater management) with a holistic view.

Building upon literature and practice that supports a flexible approach to stormwater management in urban environments that mimic natural processes and predevelopment hydrology (SuDS) as one way to, amongst others, help to prevent and adapt to climate change, the author highlights the relevance of the connection to the place for adoption of best practices that conduct towards a regenerative system. Hence, this thesis incorporates this connection to the place to the SuDS representation, naming it the SuDS 'landed rocket'.

The proposed methodology is applied by the author to a case study: Benaguasil journey towards a regenerative built environment. This urban scale case study located in the Mediterranean (Valencia, Spain) shows how, by focusing in one part of the complex system, while keeping a holistic approach, it is possible to make progress in only few years and have a promising future ahead. It can enlighten the path of other urban areas that share the same goal/vision but only see obstacles in their path.

To overcome the barriers that drag out progress, this thesis identifies and proposes two main enablers: a) a structured set of activities, the 'wheel', to guide and document the process, which is steered by a group of regional actors, the RWG, with a trans-disciplinary approach for systems-thinking, that starts with a stable small group of public policy and the academia actors, and with a shared vision grows to involve the remaining stakeholders as required (social scientists, ecologists, economists, design professions, public health experts, business institutions, civil society, community groups, the media); b) a visual and effective set of indicators, the wheel and the constellation (the SuDS 'landed rocket') maturation stage and trajectory, that monitors and assesses the progress achieved and identifies the strategies to move forward.

Integrating the views and strategies from actors at different but interconnected scales (from river basin down to individual buildings), following a structured but flexible methodology, opportunity emerges to combine efforts that catalyze the switch towards an urban built environment that supports a genuinely sustainable society.

Lessons learned through the construction, monitoring, operation and maintenance of the showcase sites will form the basis for future developments in the process of the paradigm shift leading to a broader uptake of SuDS in Spain.

4.2. Future research pathways

The work undertook within this thesis highlights the need for future research along the following lines:

- The alignment with the established regime is conducted by examining enablers and obstacles for each type of institutional work. Future research could lead to a parametric analysis being proposed for this examination.
- While the thesis focuses on the institutional work required depending on the constellation's alignment with the established regime, the methodology itself leaves the door open to embrace in the future additional tools and methods.
- Improvement of mechanisms to effectively engage stakeholders and overcome barriers that drag out progress towards regenerative urban environments.
- Extension of the monitoring activities in existing and future SuDS showcases, in particular with focus on the water-energy nexus and their long term performance (that might include extreme rainfall or a sequence of extreme events).

5. REFERENCES

Agudelo-Vera, C.M., Mels, A.R., Keesman, K.J., Rijnaarts, H.H.M. 2011. Resource management as a key factor for sustainable urban planning. J. Environ. Manage., 92, 10, 2295-2303. http://dx.doi.org/10.1016/j.jenvman.2011.05.016

Alfonso, D., Peñalvo, E., Pérez-Navarro, A., Valencia, I., 2015. Energy efficiency effects of green roofs in buildings. An experimental assessment for Mediterranean areas. Proceedings of the IWRA World Water Congress XV, Edinburgh, Scotland.

Anderson, J., Iyaduri, R., 2003. Integrated urban water planning: big picture planning is good for the wallet and the environment. Water Science and Technology : a Journal of the International Association on Water Pollution Research, 47, 7-8, 19-23.

Andrés-Doménech, I., Múnera, J.C., Francés, F., Marco, J.B., 2010. Coupling urban event-based and catchment continuous modelling for combined sewer overflow river impact assessment. Hydrol. Earth Syst. Sci., 14, 2057–2072. http://dx.doi.org/10.5194/hess-14-2057-2010.

Apostolaki, S., Jefferies, C., Wild, T., 2006. The social impacts of stormwater management techniques. Water Pract. Technol., 1, 1. http://dx.doi.org/10.2166/WPT.2006009

Arnbjerg-Nielsen, K., Willems, P., Olsson, J., Beecham, S., Pathirana, A., Bülow G., I., Madsen, H., Nguyen, V.T.V., 2013. Impacts of climate change on rainfall extremes and urban drainage systems: a review. Water Sci. Technol., 68, 1, 16-28.

Barbosa, A.E., Fernandes, J.N., David, L.M., 2012. Key issues for sustainable urban stormwater management. J. Wat. Res. 46, 6787-6798. http://dx.doi.org/10.1016/j.watres.2012.05.029

Bastien, N., Arthur, S., Wallis, S., Scholz, M., 2010. The best management of SuDS treatment trains: a holistic approach. Water Sci. Technol., 61, 1, 263-272. http://dx.doi.org/10.2166/wst.2010.806

Biddulph, M., 2011. Urban design, regeneration and the entrepreneurial city. Progress in Planning, 76, 2, 63-103. http://dx.doi.org/10.1016/j.progress.2011.08.001

Binney, P., Donald, A., Elmer, V. Ewert, J., Phillis, O., Skinner R., Young, R., 2010. IWA Cities of the Future Program. Spatial Planning and Institutional Reform Discussion Paper for the World Water Congress. Spatial Planning and Institutional Reform Working Group Report, Montreal, Canada. Last accessed 21-May-2015 from http://www.iwahq.org/contentsuite/upload/iwa/document/updated%20iwa%20spatial%20planning%20and%20institutional%20reform%20group%20montreal%20discussion%20paper.pdf

Brown, R.R., 2005. Impediments to Integrated Urban Stormwater Management: The Need for Institutional Reform. Environmental Management, 36, 3, 455-468. http://dx.doi.org/10.1007/s00267-004-0217-4

Brown, R.R., Farrelly, M.A., 2009. Delivering sustainable urban water management: a review of the hurdles we face. Water Sci. Technol. 59, 5, 839-846. http://dx.doi.org/10.2166/wst.2009.028

Brown, R.R., Keath, N., Wong, T.H.F., 2009. Urban water management in cities: historical, current and future regimes. Water Sci. Technol. 59, 5, 847-855. http://dx.doi.org/10.2166/wst.2009.029

Brown, R.R., Farrelly, M.A., Loorbach, D.A., 2013. Actors working the institutions in sustainability transitions: The case of Melbourne's stormwater management. Global Environmental Change, 23, 4, 701-718. http://dx.doi.org/10.1016/j.gloenvcha.2013.02.013

Cabrera, E., Babiano, L., 2007. La sequía en España. Directrices para minimizar su impacto. Dirección General del Agua del Ministerio de Medio Ambiente. España.

Campbell, N., D'Arcy, B., Frost, A., Novotny, V., Sansom, A., 2004. Diffuse pollution: an introduction to the problems and solutions. IWA Publishing, London. ISBN:1-900222-53-1

Casal-Campos, A., Jefferies, C., Perales-Momparler, S., 2012. Selecting SUDS in the Valencian Region of Spain. Water Pract. Technol. 7, 1, published online. http://dx.doi.org/10.2166/wpt2012.001

Castro-Fresno, D., Andrés-Valeri, V.C., Sañudo-Fontaneda, L.A., Rodriguez-Hernandez, J., 2013. Sustainable Drainage Practices in Spain, Specially Focused on Pervious Pavements. Water, 5, 1, 67–93. http://dx.doi.org/10.3390/w5010067

Charlesworth, S.M., 2010. A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. Journal of Water and Climate Change, 1, 3, 165-180. http://dx.doi.org/10.2166/wcc.2010.035

Chouli, E., Aftiasb, E., Deutscha, J.C., 2007. Applying storm water management in Greek cities: learning from the European experience. Desalination, 210, 61-68. http://dx.doi.org/10.1016/j.desal.2006.05.033

Cole, R.J., 2012. Transitioning from green to regenerative design, Building Research & Information, 40, 1, 39-53. http://dx.doi.org/10.1080/09613218.2011.610608

D'Arcy, B., Perales-Momparler, S., 2013. What to do about the rain in Spain? Developments in sustainable drainage techniques. Water 21. October.

de Haan, J.H., Rotmans, J., 2011. Patterns in transitions: Understanding complex chains of change. Technol. Forecast. Soc. Change., 78, 90-102. http://dx.doi.org/10.1016/j.techfore.2010.10.008

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, Official Journal (OJ L 327). 2000.

du Plessis, C., 2012. Towards a regenerative paradigm for the built environment. Building Research & Information, 40, 1, 7-22. http://dx.doi.org/10.1080/09613218.2012.628548

Duffy, A. and Jefferies, C. 2011. Research Report: Developing a Framework to guide Urban Water Systems Transitions. SWITCH Deliverable D1.1.1. Last accessed on 13-May-2014 from http://www.switchurbanwater.eu/outputs/pdfs/W1-3_GEN_MAN_D1.3.3_SWITCH_Transition_Framework.pdf

Elzen, B., Geels, F.W., Leeuwis, C.S., Van Mierlo, B., 2011. Normative contestation in transitions 'in the making': animal welfare concerns and system innovation in pig husbandry (1970–2008). Research Policy, 40, 263-275. http://dx.doi.org/10.1016/j.respol.2010.09.018

Escuder-Bueno, I., Andrés-Doménech, I., Morales-Torres, A., Perales-Momparler, S., 2013. Towards energy efficiency improvement in urban areas stormwater management: the E2STORMED project [in Spanish], in: Vallés-Morán, F.J., Andrés-Doménech, I., Escuder-Bueno, I., López-Jiménez, P.A., Marco S., J.B. (Eds), 2013, III Jornadas de Ingeniería del Agua. La protección contra los riesgos hídricos. Vol 2, pp. 51-58. ISBN:978-84-267-2071-9

European Commission, 2010. Toledo reference document on integrated urban regeneration and its strategic potential for a smarter, more sustainable and socially inclusive urban development in Europe. Toledo, 22 June 2010. Last accessed 24-April-2015 from http://ec.europa.eu/regional_policy/archive/newsroom/pdf/201006_toledo_declaration_en.pdf.

European Commission, 2012. Guidelines on Best Practices to Limit, Mitigate or Compensate Soil Sealing. Commission Staff Working Document. SWD(2012) 101 final/2. Brussels. Last accessed 21-May-2014 from http://ec.europa.eu/environment/soil/pdf/guidelines/EN%20-%20Sealing%20Guidelines.pdf

Febles, D., Perales, S. y Soto, R. ,2009. Innovación y Sostenibilidad en la Gestión del Drenaje Urbano: Primeras Experiencias de SuDS en la Ciudad de Barcelona. Jornadas de Ingeniería del Agua. CEDEX. Madrid. 27-28 Octubre 2009.

Ferguson, B.C., Brown, R.R., Deletic, A., 2013. Diagnosing transformative change in urban water systems: Theories and frameworks. Global Environmental Change 23, 264-280. http://dx.doi.org/10.1016/j.gloenvcha.2012.07.008

Ferguson, B.C., Brown, R.R., de Haan, F.J., Deletic, A., in press. Analysis of institutional work on innovation trajectories in water infrastructure systems of Melbourne, Australia. Environ. Innovation Soc. Transitions, In Press. http://dx.doi.org/10.1016/j.eist.2013.12.001

Frantzeskaki, N., Loorbach, D., Meadowcroft, J., 2012. Governing societal transitions to sustainability. International Journal of Sustainable Development, 15, 1/2, 19-36. http://dx.doi.org/10.1504/IJSD.2012.044032

Gasper, R., Blohm, A., Ruth, M., 2011. Social and economic impacts of climate change on the urban environment. Current Opinion in Environmental Sustainability, 3, 150-157. http://dx.doi.org/10.1016/j.cosust.2010.12.009

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy, 36, 3, 399-417. http://dx.doi.org/10.1016/j.respol.2007.01.003

Grau E., A., 1995. Benaguasil during the ancient regime [In Valencian]. Ilmo. Ayuntamiento de Benaguasil, Valencia. ISBN:84-606-2634-2.

Halpin, E., Escuder, I., 2015. Smart governance of infrastructure programs: facing the next generation of challenges and succeeding. Proceedings of the 25 ICOLD Congress. Norway.

Hamel, P., Daly, E., Fletcher, D., 2013. Source-control stormwater management for mitigating the impacts of urbanisation on baseflow: A review. Journal of Hydrology, 485, 201-211. http://dx.doi.org/10.1016/j.jhydrol.2013.01.001

Jefferies C., Duffy A.M., 2011. The SWITCH Transition Manual. ISBN 978-1-899796-23-6. Last accessed 13-May-2014 from http://www.switchurbanwater.eu/outputs/pdfs/W1-3_GEN_MAN_D1.3.4_SWITCH_Transition_Manual.pdf

Jones, P.S., Davis, A.P., 2012. Spatial Accumulation and Strength of Affiliation of Heavy Metals in Bioretention Media. J. Environ. Eng., 139(4), 479–487. http://dx.doi.org/10.1061/(ASCE)EE.1943-7870.0000624

Lamera, C., Becciu, G., Rulli, M.C., Rosso, R., 2014. Green roofs effects on the urban water cycle components. J. Pro. Eng. 70, 988-997. http://dx.doi.org/10.1016/j.proeng.2014.02.110

Loorbach, D.A., 2007. Transition Management: New mode of Governance for sustainable development. PhD, Erasmus University, Rotterdam. ISBN: 978-905727-057-4. Last accessed 13-May-2014 from http://repub.eur.nl/pub/10200

Loorbach, D., Rotmans, J., 2010. The practice of transition management: Examples and lessons from four distinct cases. Futures 42, 3, 237-246. http://dx.doi.org/10.1016/j.futures.2009.11.009

Lundy, L., Wade, R., 2011. Integrating sciences to sustain urban ecosystem services. Progress in Physical Geography, 35, 5, 653-669. . http://dx.doi.org/10.1177/0309133311422464

Madrid City Council, 2006. Ordenanza de Gestión y Uso Eficiente del Agua en la Ciudad de Madrid. BO. Ayuntamiento de Madrid 22/06/2006 núm. 5709. p. 2410-2443.

Mang, N.S., 2009. Toward a Regenerative Psychology of Urban Planning. Saybrook Graduate School and Research Center, ProQuest, UMI Dissertations Publishing, 3368975. Last accessed 21-May-2014 from http://gradworks.umi.com/33/68/3368975.html

Mang, P., Reed, B., 2012. Designing from place: a regenerative framework and methodology, Building Research & Information, 40, 1, 23-38. http://dx.doi.org/10.1080/09613218.2012.621341

Marsalek, J., Chocat, B., 2002. International Report: Stormwater management. Water Sci. Technol., 46, 6-7, 1-17.

McCormick, K., Anderberg, S., Coenen, L., Neij, L., 2013. Advancing sustainable urban transformation. J. Clean Prod., 50, 1-11. http://dx.doi.org/10.1016/j.jclepro.2013.01.003

Næss, P., Vogel, N. 2012. Sustainable urban development and the multi-level transition perspective. Environ. Innovation Soc. Transitions, 4, 36-50. http://dx.doi.org/10.1016/j.eist.2012.07.001

Nevens, F., Frantzeskaki, N., Gorissen, L., Loorbach, D., 2013. Urban Transition Labs: co-creating transformative action for sustainable cities, J. Clean Prod., 50, 111-122. http://dx.doi.org/10.1016/j.jclepro.2012.12.001.

Novotny, V., Ahern, J., Brown, P., 2010. Water centric sustainable communities: planning, retrofitting, and building the next urban environment. John Wiley & Sons, Inc. New Jersey. ISBN 978-0-470-47608-6

Pahl-Wostl, C., Tàbara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E., Ridder, D., Taillieu, T., 2008. The importance of social learning and culture for sustainable water management. Ecological Economics, 64, 3, 484-495. http://dx.doi.org/10.1016/j.ecolecon.2007.08.007

Pedersen-Zari, M., 2012. Ecosystem services analysis for the design of regenerative built environments. Building Research & Information, 40, 1, 54-64. http://dx.doi.org/10.1080/09613218.2011.628547

Perales, S., Andrés, I., 2008. Sustainable Urban Drainage Systems: An alternative for Stormwater Management [In Spanish]. Revista Técnica de Medio Ambiente C&M Publicaciones, Madrid, pp. 92–104. ISSN:1130-9881

Perales, S., Valls, G., Coombs, P., 2011. Pluvial flood hazard maps: tools and case studies [In Spanish], in: Escuder-Bueno, I., Matheu, E., ltarejos-García, L., Castillo-Rodríguez, J.T. (Eds), 2012, Risk Analysis, Dam Safety, Dam Security and Critical Infrastructure Management, Taylor & Francis Group, London, pp. 129-137. ISBN 978-0-415-62078-9.

Perales-Momparler, S., Soto Fernández, R. 2013. Runoff management integration into Barcelona landscape: urban regeneration interventions. In: Vallés-Morán, F.J., Andrés-Doménech, I., Escuder-Bueno, I., López-Jiménez, P.A., Marco, J.B. (Eds.), 2013, III Jornadas de Ingeniería del Agua, La protección contra los riesgos hídricos, vol. 2, ISBN 978-84-267-2071-9, pp. 147-154 (in Spanish).

Perales-Momparler, S., Valls-Benavides, G., 2013. Sustainable Drainage Systems (SuDS). Paisea nº 024: Espacios del Agua. Paisea revista s.l. ISSN 1887-2557

Potter, K., Ward, S., Shaw, D., Macdonald, N., White, I., Fischer, T., Butler, D., Kellagher, R., 2011. Engineers and planners: sustainable water management alliances. Engineering Sustainability, 164, ES4, 239-247. http://dx.doi.org/10.1680/ensu.2011.164.4.239

Progress Consulting S.r.l. and Living Prospects Ltd., 2011. The role of regional and local authorities in promoting a sustainable water policy. Final Survey Report. Doc cdr-180. European Union. Last accessed 13th-May-2015 from http://portal.cor.europa.eu/europe2020/news/Documents/Water/Water%20Survey%20Full%20Report%20Final.pdf

Puertas, J.; Suárez, J.; Anta, J. Gestión de las aguas pluviales. Implicaciones en el diseño de los sistemas de saneamiento y drenaje urbano. CEDEX. Gobierno de España (2008).

Rauch., W., Seggelke, K., Brown, R., Krebs, P., 2005. Integrated Approaches in Urban Storm Drainage: Where Do We Stand? Environmental Management, 35, 4, 396–409. http://dx.doi.org/10.1007/s00267-003-0114-2

Reed, B., 2007. Shifting from 'sustainability' to regeneration. Building Research & Information, 35, 6, 674-680. http://dx.doi.org/10.1080/09613210701475753

Resolution of 31st October 2013, of the Infrastructure, Territory and Environment Regional Ministry, submitting to public information the revision of the Territorial Action Plan on Flood Risk prevention for the Valencian Region [In Spanish]. Diario Oficial de la Comunidad Valenciana 2013, 7159, 34289-34290.

Rotmans, J., Kemp, R., van Asselt, M., 2001. More evolution than revolution: transition management in public policy. Foresight, 3, 1, 15-31. http://dx.doi.org/10.1108/14636680110803003

Royal Decree 1290/2012 of 7th September amending both the Royal Decree 849/1986 of 11 April, approving the Regulation of Public Water, and Royal Decree 509/1996 of 15 March, developing the Royal Decree Law 11/1995 of December 28, laying down rules for urban waste water treatment [in Spanish]. Boletín Oficial del Estado 2012, 227, 66167–66194.

Royal Decree 233/2013 of 5th April regulating the National Plan to encourage house renting, building refurbishment and urban regeneration and renovation, 2013-2016 [in Spanish]. Boletín Oficial del Estado 2013, 86, 26623–26684.

Rueda Palenzuela, S., 2009. Libro Verde del Medio Ambiente Urbano. Tomo II. Ministerio de Medio Ambiente y Medio Rural y Marino. España.

Sánchez-Rodríguez, R., 2009. Learning to adapt to climate change in urban areas. A review of recent contributions. Current Opinion in Environmental Sustainability, 1, 2, 201-206. http://dx.doi.org/10.1016/j.cosust.2009.10.005

Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Research Policy, 41, 6, 1025-1036. http://dx.doi.org/10.1016/j.respol.2011.12.012

Terzakis, S., Fountoulakis, M.S., Georgaki, D., Albantakis, D., Sabathianakis, I., Karathanasis, A.D., Kalogerakis, N., Manios, T., 2008. Constructed wetlands treating runoff in the central Mediterranean region. Chemosphere 72, 141-149. http://dx.doi.org/10.1016/j.chemosphere.2008.02.044.

Tukker, A., Butter, M., 2007. Governance of sustainable transitions: about the 4(0) ways to change the world. J. Clean Prod., 15, 1, 94-103. http://dx.doi.org/10.1016/j.jclepro.2005.08.016

United States Environmental Protection Agency (USEPA), 2008. Managing wet weather with Green Infrastructure. Green Streets. Low Impact Development Center, EPA, USA. Last accessed 21-May-2014 from http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_munichandbook_green_streets.pdf

van der Brugge, R., Rotmans, J., 2007. Towards transition management of European water resources. Water Resour. Manag., 21, 1, 249-267. http://dx.doi.org/10.1007/s11269-006-9052-0

van der Steen, P., Howe, C., 2009. Managing water in the city of the future; strategic planning and science. Rev. Environ. Sci. Biotechnol., 8, 115–120. http://dx.doi.org/10.1007/s11157-009-9154-2

van Herk, S., Zevenbergen, C., Ashley, R., Rijke, J., 2011. Learning and Action Alliances for the integration of flood risk management into urban planning: a new framework from empirical evidence from The Netherlands. Environmental Science & Policy, 14, 5, 543-554. http://dx.doi.org/10.1016/j.envsci.2011.04.006

Willems, P., Olsson, J., Arnbjerg-Nielsen, K., Beecham, S., Pathirana, A., Bülow G., I., Madsen, H., Nguyen, V.T.V., 2012. Impacts of Climate Change on Rainfall Extremes and Urban Drainage Systems. IWA Publishing. ISBN: 9781780401256

Wong, T.H.F., Brown, R.R., 2009. The water sensitive city: principles for practice. Water science and technology, 60, 3, 673-682. http://dx.doi.org/10.2166/wst.2009.436

Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray R.; Shaffer, P., 2007. The SUDS Manual. CIRIA C697. London. ISBN:978-0-86017-697-8

Woolthuis, R., Hooimeijer, F., Bossink, B., Mulder, G., Brouwer, J., 2013. Institutional entrepreneurship in sustainable urban development: Dutch successes as inspiration for transformation. J. Clean Prod., 50, 91-100. http://dx.doi.org/10.1016/j.jclepro.2012.11.0

Xunta de Galicia, Aguas de Galicia y Empresa Pública de Obras e Servicios Hidráulicos 2009. Instruciones técnicas para obras hidráulicas en Galicia. ITOHG-SAN-1/4.

ANNEXES

ANNEX 1: A regenerative urban stormwater management methodology: the journey of a Mediterranean city.

Abstract

Urban drainage patterns are altered by increasing urbanization and rapid conveyance and discharge of runoff, leading to increased flood risk, diminish of aquifer recharge and degradation of receiving waterways. These effects are expected to escalate with climate change. In response, alternative and more sustainable drainage practices with a holistic approach have been developed, although their wide-scale implementation has been limited largely due to socio-institutional barriers. This paper presents an innovative regenerative urban stormwater methodology for transition management at city level, containing two main enablers to overcome the barriers that drag out progress. First, a structured set of activities, the 'wheel', to guide and document the process, which is steered by a group of regional actors. Then, a visual and effective set of indicators that monitors and assesses the progress achieved and identifies the strategies to move forward. Its successful application to Benaguasil, a Mediterranean city, reveals that by integrating the views and strategies from actors at different but interconnected scales and following a structured but flexible methodology, it is possible to make progress in only few years and have a promising future ahead.

Keywords

Built environment, Mediterranean cities, Regenerative, SuDS, Transition management, Urban stormwater management.

Abbreviations

CSOs, combined sewer overflows; **DST**, decision support tool; **ERDF**, European regional development fund; **RWG**, regional working group; **SuDS**, sustainable drainage systems; **USWM**, urban stormwater management.

1. Introduction

Urban drainage patterns are altered by increasing urbanization and soil sealing, leading to increased flood risk and diminish of aquifer recharge (European Commission, 2012). Traditional practice in many countries considers urban stormwater as a waste product instead of a precious resource, and its rapid conveyance and discharge contributes to the degradation of receiving waterways: combined sewer overflows (CSOs), diffuse pollution, etc. (Andrés-Doménech et al., 2010; Campbell et al., 2004). These effects are expected to escalate with climate change: extreme rainfall changes in the range 10-60% may lead to changes in flood and CSOs frequencies and volumes in the range 0-400% depending on the system characteristics (Willems et al., 2012); action cannot be further delayed and needs to be taken with an adaptive approach that involves, in addition to investments, active learning and consideration of the interrelationship of the economic and social challenges facing cities around the world (Arnbjerg-Nielsen et al., 2013; Gasper et al., 2011).

In response, alternative and more sustainable drainage practices with a holistic approach (also considering energy efficiency, social amenity, biodiversity, urban heat island effect, etc.) promoting sustainable urban drainage systems (SuDS) have been developed and implemented in many cities in the last 20-30 years (Marsalek and Chocat, 2002; Novotny et al., 2010), although only a limited acceptance can be found around the Mediterranean (Castro-Fresno et al., 2013; Charlesworth et al., 2013; Chouli et al., 2007; Perales-Momparler and Valls-Benavides, 2013), where there is a need to create showcases to demonstrate the feasibility and suitability of new solutions in the long term (Casal-Campos et al., 2012).

Despite the multiple benefits of SuDS (Apostolaki et al., 2006; Charlesworth, 2010; Lundy and Wade, 2011; USEPA, 2008), their wide-scale implementation has been limited (Brown, 2005), with many cities investing heavily in the conventional approach (Wong and Brown, 2009). Insights from different studies on integrated urban water management reveal that barriers are largely socio-institutional rather than technical (Brown and Farrely, 2009; Rauch et al., 2005) and recommendations call for collaborative planning and multi-stakeholders platforms that involve civil society (Potter et al., 2011; Sanchez-Rodriguez, 2009; van Herk et al., 2011) to deliver a shared vision for the cities of the future (Binney et al., 2010).

Hence, a radical change is required in culture as well as institutions (Pal-Wostl et al., 2008) in order to limit and potentially reverse damage to ecosystems (Pedersen-Zari, 2012). Consideration must be given to the interrelationship of urban stormwater management (USWM) with other sectors (e.g. energy, transport, urban planning, health) (du Plessis, 2012) through a systems thinking, building capacity, building natural and social capital approach, which are the aspirations of regenerative design and development (Cole, 2012b).

Transition management emerges in the literature as a sound governance approach to bring about the required change of paradigm (Frantzeskaki et al., 2012; Tukker and Butter, 2007).

However, there is a need for research that puts cities in focus rather than countries or buildings (Cole, 2012b; McCormick et al., 2013). Existing conceptual models need to be updated and improved to address the complex reality of urban areas (Ferguson et al., 2013a; Sanchez-Rodriguez, 2009), and the question of what tactical and operational transition management looks like needs to be addressed (Loorbach and Rotmans, 2010). With much of the literature focusing on barriers to change, successful case studies are required (Brown et al., 2009) with positive vision and narratives to encourage collective action to solve environmental problems (Smith and Raven, 2012), transitioning towards regenerative urban built environments.

The aim of this paper is therefore to develop a methodology, with a conceptual framework, specific method and tools, placing the focus on municipal infrastructure systems or sub-systems (USWM in this case). With a place-based holistic view, the proposed methodology allows for the understanding and the characterization of the current situation in a process that guides future actions to move towards the desired regenerative urban built environment concept.

This methodology has been applied to Benaguasil, a Mediterranean city where stormwater management is the local authority's responsibility but has been historically guided by mainstream conventional drainage practices. The paper shows how, by taking a multi-dimensional and trans-disciplinary approach to solve environmental problems, future actions can be properly addressed. Working with academia has been essential to develop wider evidence base (Hoxie et al., 2012). In this case, a sequence of research projects has advanced the innovative approach to stormwater management in Benaguasil, but it is contended that this methodology could be applied to any urban context.

2. Proposed methodology

Under the well-known slogan 'think global, act local', cities in the 21st century face the enormous challenge of catalyzing, intensifying and accelerating sustainable urban transformations, that can be defined in two dimensions: first, drivers of 'radical' change, such as governance and planning, innovation and competitiveness, and lifestyle and consumption; and, second, 'multi-dimensional' sustainable urban structures, which include resource management and climate mitigation and adaptation, transport and accessibility, buildings, and the spatial environment and public space (McCormick et al., 2013).

Without losing this holistic view, the methodology presented herein places the focus on 'resource management and climate mitigation and adaptation', in particular in USWM, proposing processes that can bring about the required change, shaped by the place-based approach of the regenerative sustainability paradigm (Mang and Reed, 2012).

2.1. SuDS as a regenerative development instrument

A relatively new and flexible approach to urban stormwater management has emerged that makes a switch from piped engineered systems to practices and systems that use and enhance natural processes (infiltration, evapotranspiration, filtration, retention, reuse) to mimic the site predevelopment hydrology.

Known under different names across the globe, the term Sustainable Drainage Systems (SuDS) is used throughout this article to refer to this approach. SuDS currently in use include green roofs, rain gardens, permeable pavements, infiltration basins and daylighting of culverted water bodies; they can be combined with conventional techniques (pipes) and retrofitted into existing drainage systems. While conventional drainage focuses on stormwater quantity management (rapid collection and conveyance to receiving bodies, without previous treatment in many cases), SuDS place equal emphasis on water quantity, water quality, amenity and biodiversity, the three spheres of the SuDS 'triangle' (Woods-Ballard et al., 2007). In addition, there are other benefits that SuDS can provide (specially the vegetated devices) that are important to consider in a changing climate. Carbon sequestration and storage, urban cooling, flood resilience, human-health and well-being have been incorporated by Charlesworth (2010) into the representation of SuDS, baptizing the new one as the SuDS 'rocket'.

Best practice utilizes a chain of SuDS devices, a 'management train', to mimic natural catchment processes as closely as possible. This prioritizes prevention and control of water at source (i.e. green roofs, pervious pavements, bioretention areas) before considering site or regional controls (i.e. wetlands, ponds) (Woods-Ballard et al., 2007), although this is not always the approach followed in practice (Bastien et al., 2010). In mimicking nature, SuDS can provide 'ecosystem services' such as water resources, flood protection, biodiversity, climatic regulation, recreation, aesthetic inspiration, opportunities for social interaction, stress reduction, environmental education, healthier and more livable cities (Apostolaki et al., 2006; Jones and Davis, 2012; Hamel et al., 2013; Novotny et al., 2010), contributing to the positive integration with, and restoration of, local ecosystems (Pedersen-Zari, 2012), and can help cities transition towards more sustainable environments which are more resilient to changing future conditions (Lundy and Wade, 2011).

However, it is important to integrate strategic resource management with urban spatial planning (Agudelo-Vera et al., 2011), which for stormwater management includes adapting urban layout to existing water corridors and patterns (Perales et al., 2011). Moreover, promotion of character in townscape and landscape "rooted in the context and its social-ecological narratives" (du Plessis, 2012) must be embraced by the different agencies working in the region (Biddulph, 2011). Hence, a new representation for the regenerative approach to stormwater management is proposed: the SuDS 'landed rocket' (Fig. 1). In doing so, we incorporate the connection to the place, in a way that people "are vitalized and become intrinsically motivated to care for it" as a result, bringing about "the transformation of our cities into places that are life enhancing and regenerative" (Mang, 2009).

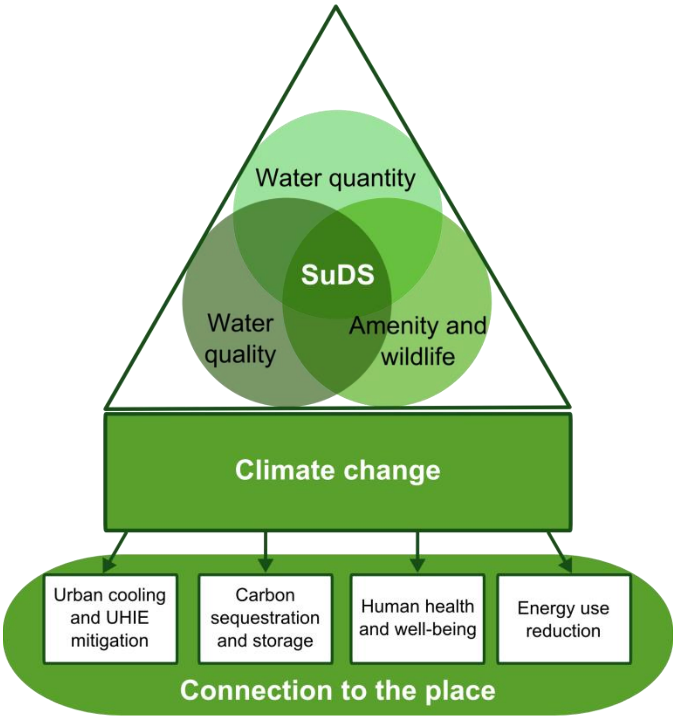


Fig. 1. *The SuDS landed rocket (after Woods-Ballard et al. (2007) and Charlesworth (2010)).*

From the above, we understand that, if properly designed and integrated, SuDS could comply with the three insights that form the basis of the regenerative paradigm (du Plessis, 2012): a) necessity to follow a development approach based on how nature works; b) interpretation of the world as an ever-changing, impermanent and inherently unpredictable set of processes; and, c) the notion that humans participate in the production, transformation and evolution of the ecosystem in which they find themselves.

The desired transformation of cities, from the lens of USWM while understanding the breath of the whole system, is depicted conceptually in Fig. 2. It builds on work by Reed (2007) and incorporates four representations of stormwater practices nested into the SuDS 'landed rocket' (Fig. 1). They relate to the nested levels of progression towards a regenerative design: while green design is primarily directed at doing 'less harm', sustainability is a 'neutral' state that provides the necessary base condition to permit regenerative capabilities to evolve (Cole, 2012b). Regeneration is about engaging the "entirety of what makes a place healthy", entering an 'evolutionary spiral' in which three essential aspects catalyze the design process: "understanding the master pattern of place; translating the patterns into design guidelines and conceptual design; and, ongoing feedback – a conscious process of learning and participation through action, reflection and dialogue" (Reed, 2007).

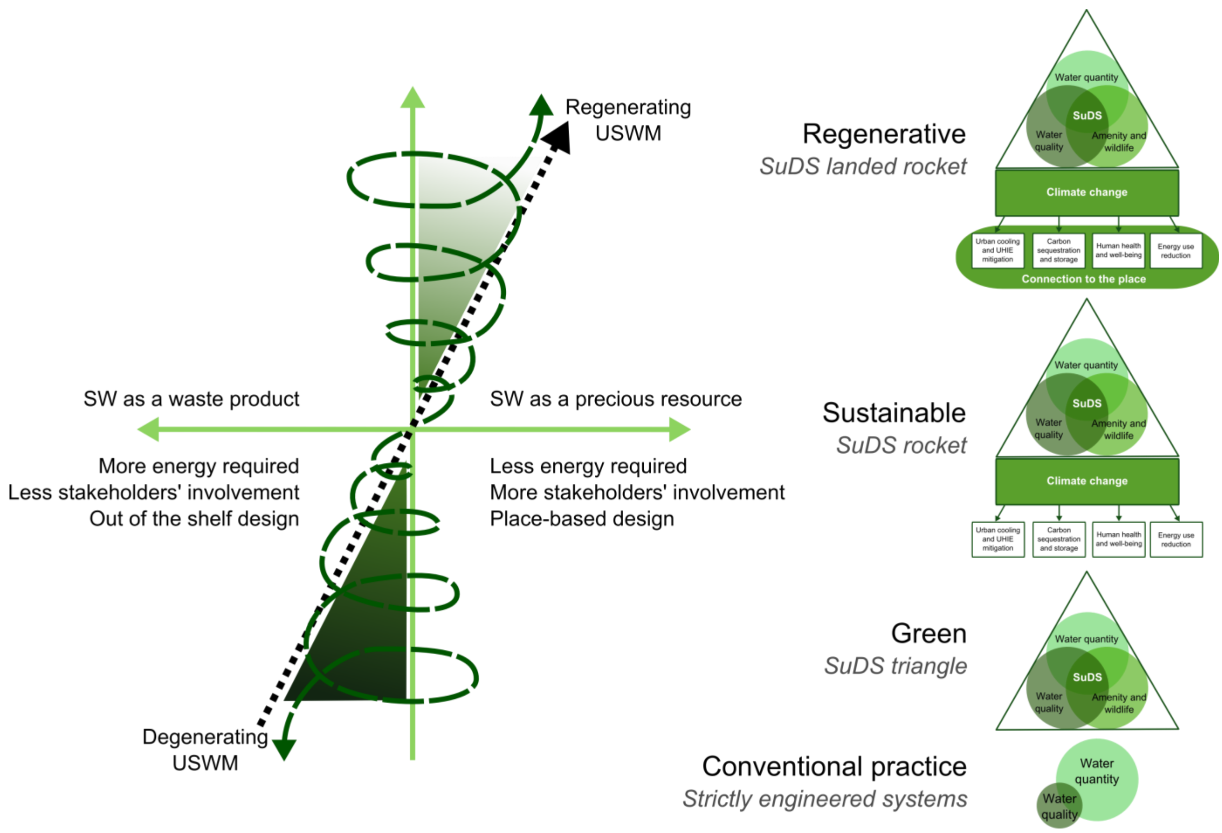


Fig. 2. *Trajectory of Environmentally Responsible Stormwater Management (after Reed (2007)).*

The 'Leapfrogging' concept (Jefferies and Duffy, 2011) applies to Fig. 2. Cities currently in the lower part of the trajectory could find paths to avoid intermediate practices (i.e. going directly from conventional practices to regenerative ones for new and retrofitting schemes), and developing cities could avoid mistakes and limitations of the slow route.

2.2. Steering the wheel: the 'sustainable transition management cycle'

Sustainable transitions such as those which move towards a regenerative approach to stormwater management have additional complexities to many historical transitions, as they are goal-oriented, addressing persistent and new environmental collective problems, which with achievement do not offer obvious local, immediate, visible and tangible user benefits (Geels, 2011). In addition, scale and context-dependencies of cities present huge challenges to a transition toward sustainability/regeneration (Næss & Vogel, 2012). This makes the participation of public authorities and civil society crucial to a sustainable transition (Elzen et al., 2011).

Governance and planning, in particular the way for stakeholders to collaborate, have been identified as critical to transformative change towards urban sustainability (McCormick et al., 2013), and transition management emerges as an innovative approach for dealing with the complex, uncertain and multi-facetted problems of water management (van de Brugge and Rotmans, 2007).

SWITCH (Sustainable Water Improves Tomorrow's Cities Health) was an EU funded action research program which overall goal was to catalyze change towards more sustainable urban water management in the 'City of the Future' (van der Steen and Howe, 2009). A final output of this project is 'The SWITCH Transition Manual', whose purpose is "to provide a coherent methodology to enable a city to change its water system from today's state into a better condition in the future" (Jefferies and Duffy, 2011).

In the methodology presented in this paper, we make use of part of the SWITCH project transition framework to guide the cities' 'regenerating trajectory', which has been selected for its city-water approach that builds on transition theory. 'Steering the wheel' should not be viewed as a way to control societal changes; by contrast it is a method for the exploration in a reflexive manner of a new city governance approach (Nevens et al., 2013).

Building upon four different approaches to transitioning (the multi-phase concept, the multi-level perspective, transition management and strategic niche management), the 'SWITCH Transition Framework' (Duffy and Jefferies, 2011) is intended for decision makers at national and local scales, being of great assistance also to urban water practitioners and decision makers in the urban water sector.

At the core of the framework, lies the so called 'Sustainable Transition Management Cycle', which consists of ten activities that take place at three management levels (Fig. 3): Strategic, where long-term ambitions and goals are formulated, requiring strategic thinkers that are open to change and reflection; Tactical, aiming to gain societal support and attention for sustainability objectives and intermediary goals, by developing networks and coalitions that can identify and overcome structural barriers; and, Operational, based on short-term experimenting with innovations that have potential to materialize the strategic vision, informing actors about specific barriers in different environments (Loorbach, 2007). These levels do not represent a hierarchy and although different types of actors participate at each level, a diverse set of competencies and skills are required across all levels (Jefferies and Duffy, 2011).

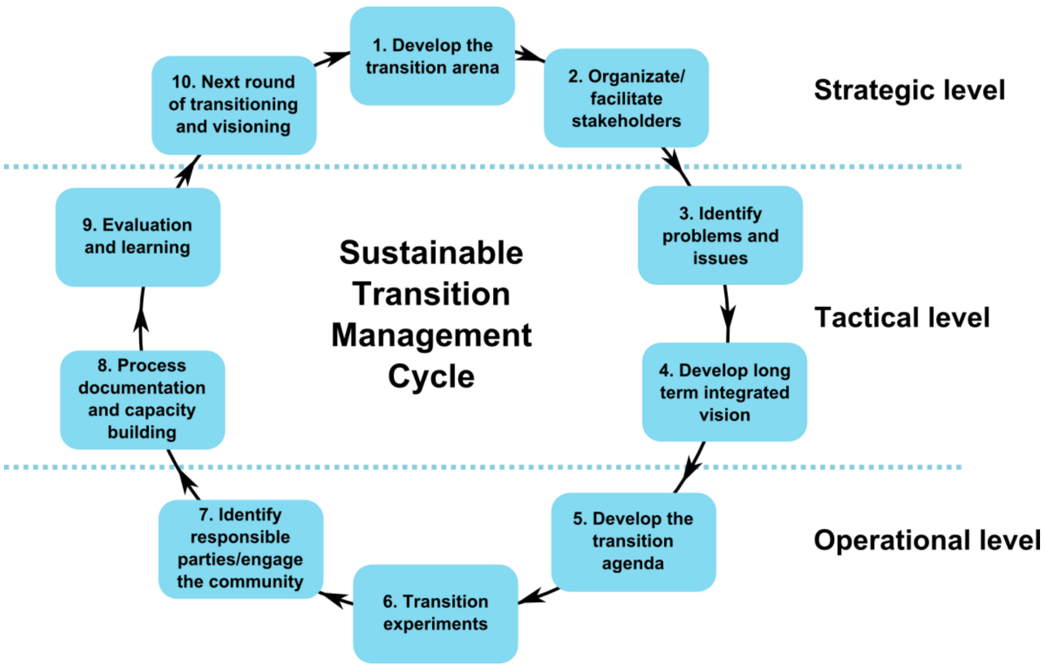


Fig. 3. *The sustainable transition management cycle (Adapted from Duffy and Jefferies (2011)).*

The Sustainable Transition Management Cycle is driven by the SWITCH so called ‘Learning Alliance’, a stakeholders group made up from government bodies, user groups and research institutions that bring new ideas, techniques and innovations into a city, and has strong powers of influence in commissioning and nurturing projects that demonstrate the implications of the transition being promoted in the city. Throughout this paper, the Sustainable Transition Management Cycle will be referred to as the ‘wheel’, whereas the ‘Learning Alliance’ will be the Regional Working Group (RWG). A frontrunner capable of effectively engaging relevant stakeholders in the region is crucial for the creation and coordination of a RWG that endures over time.

We propose to use the ‘wheel’ to classify the activities carried out in the case study, so an assessment can be made of the strengths developed over time as a way to ‘measure’ the progress achieved along the transition pathway. The numbering of the activities does not imply any implementation order, as strengths can be developed in any sequence. However, numbers have been added in Fig. 3 to facilitate the consequent analysis.

2.3. Institutional work on innovation trajectories

Barriers to advancing sustainable urban water management have been identified as largely socio-institutional rather than technical (Brown and Farrely, 2009), justifying placing the focus on institutions (Geels, 2004), the actors and their strategies when analyzing socio-technical transitions to sustainability (Díaz et al., 2013). Brown et al. (2013) highlight the importance of institutional work on transition management, suggesting that "more emphasis should be given to this interplay between frontrunners, visions and experiments on the one hand and institutional strategies and structures on the other". Hence, the formation of new networks such as the RWG, where each member can be a frontrunner in their institution, plays an important role in framing sustainable urban development (Woolthuis et al., 2013).

Although it is common to represent transitions at the system scale (Geels and Schot, 2007), we focus our transition analysis on one part of the system (Loorbach and Rotmans, 2010), i.e., USWM versus urban water management. Furthermore, conceptualizing the SuDS 'landed rocket' as an individual 'constellation' within the USWM system, it is possible to identify what type it is according to its 'degree of influencing' ('share of power') of the overall system (de Haan and Rotmans, 2011): regimes are the most powerful, niche-regimes have moderate power, niches have low power and pre-niches have no power. This classification has been used by Ferguson et al. (in press) to identify the stage of maturation of an individual constellation over time, using the multi-phase S-curve (Rotmans et al., 2001) and its four stages of a transition: pre-development, take-off, acceleration and stabilization. Consequently, when identifying the maturation stage of the constellation of study and its alignment with the established regime, work by Ferguson et al. (in press) provides some light on the type of institutional work required to support the innovation maturation (Fig. 4).

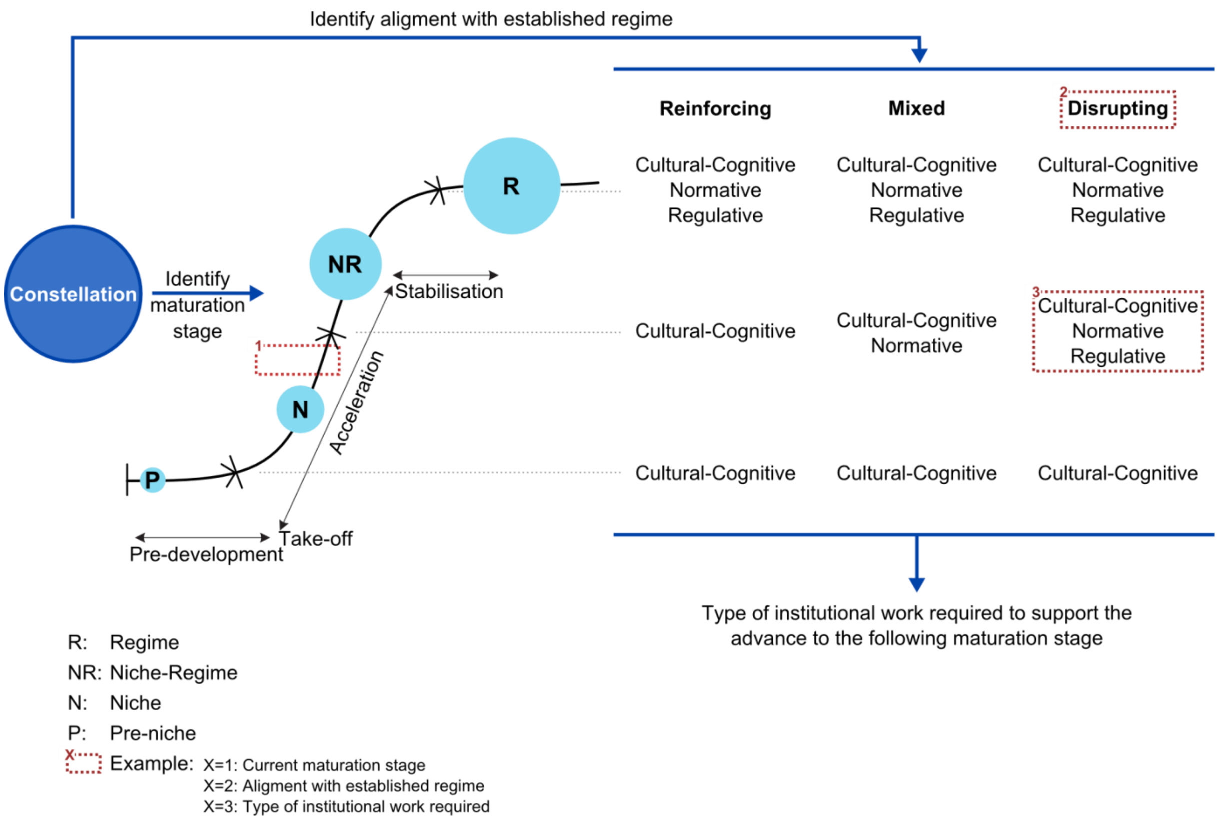


Fig. 4. *Identification of the type of institutional work required for supporting key maturity stages (Adapted from Ferguson et al. (in press)).*

To complete the analysis, we use the classification of 'institutional work' by Ferguson et al. (in press) to present enablers and barriers found in the case study, and compare them with the main type of barriers found by Brown and Farrely (2009).

2.4. A regenerative urban stormwater management methodology

The methodology we propose for approaching the concept of regenerative urban built environment focuses on municipal infrastructure systems or sub-systems (in this case USWM) with a holistic view. This is a step forward from the more common situation where it is applied to buildings or particular developments (Cole, 2012b). It is intended to be used at a local level, with a place-based approach that integrates and frames planetary issues (such as energy and global warming) "in manageable, meaningful and, literally, grounded context" (Reed, 2007).

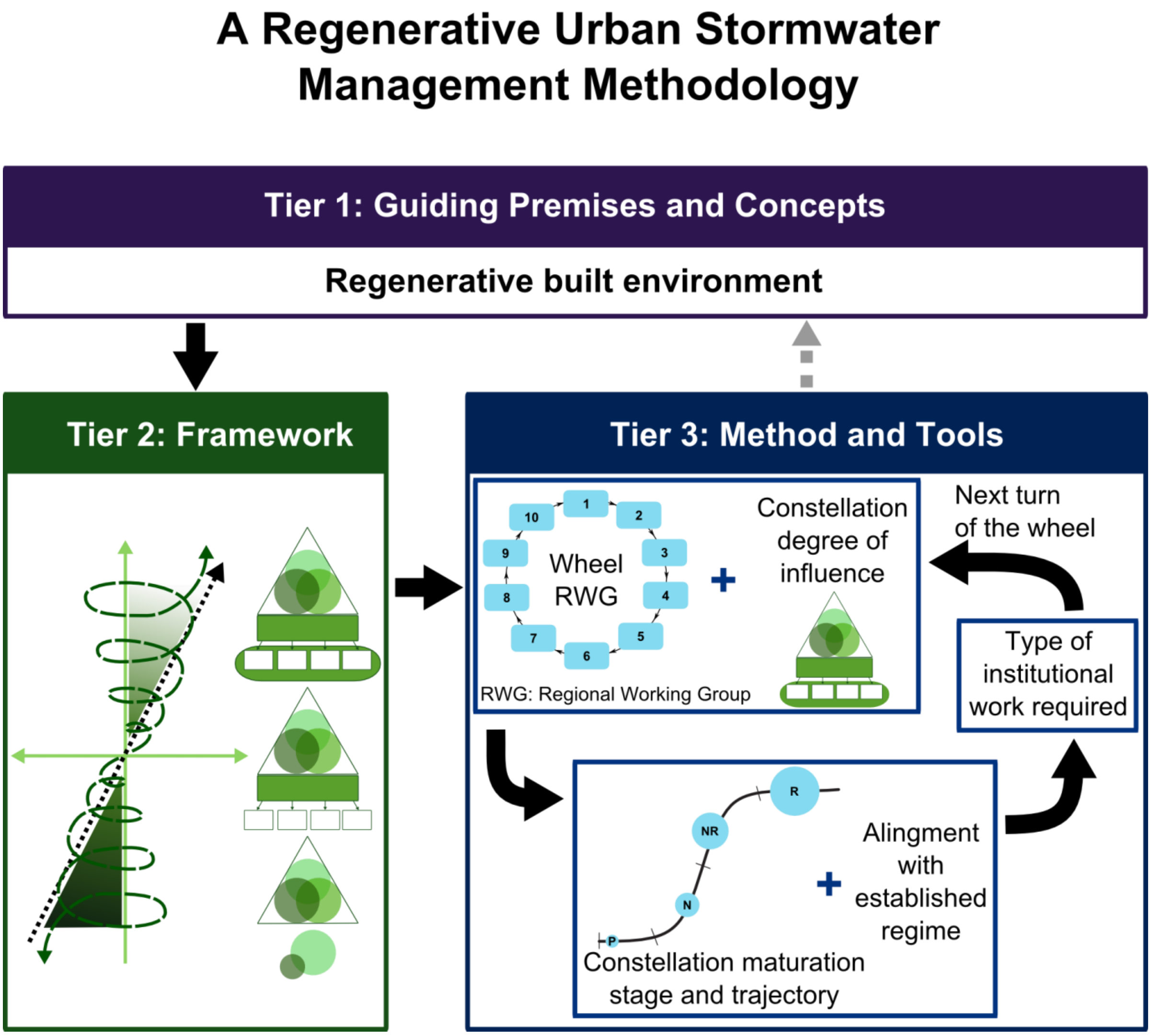


Fig. 5. *A regenerative urban stormwater management methodology. Solid arrows show the route between tiers and link the cyclical steps within Tier 3. The dashed arrow represents the possibility to refine concepts during the process.*

This methodology (Fig. 5) is based on that proposed by Mang and Reed (2012), adapted to deal with USWM, and includes the framework and the method and tools previously described in this section, with the aim of advancing the SuDS 'landed rocket' (the constellation) within the vision of a regenerative built environment. It is structured in 3 tiers: Tier 1 presents the thinking behind tiers 2 and 3, the desired paradigm: a regenerative built environment; Tier 2 depictures the theoretical framework (Fig. 2), that enables comprehending and visioning of the complex systems analyzed, USWM in this case; and, Tier 3 provides practical method and tools for advancing in the desired direction, "engaging the people who will need to sustain and develop the process over time" (Mang and Reed, 2012).

A theoretical application of this framework would start in Tier 1 by defining which is the desired paradigm and continue with depicting the framework to journey towards it, Tier 2. Then the proposed method and tools presented in Tier 3 would be followed in a cyclical way, starting from scratch. However, real cities might have travelled part of the journey without framing it within a conceptual model and formal definition of Tiers 1 and 2 could happen on the way. This is what happened in Benaguasil, the case study presented in sections 3 and 4. In addition, progress within Tier 3 could suggest refinements of concept in Tiers 1 and 2 (e.g. adding a new parameter along the x axis in Fig. 2).

In Tier 3, the first step is to examine the strengths already developed within the wheel activities (Fig. 3) and the relative degree of influence of the SuDS 'landed rocket' within the current USWM system. This analysis allows depicting the stage within the constellation maturation curve and the alignment with the established regime at present. Consequently, the type of institutional work required for supporting key maturity stages is identified (Fig. 4), which can be linked to particular activities programmed to develop strengths within the wheel. After a period of time, the analysis will be conducted again, assessing the progress achieved and planning the following turn of the wheel.

Strengths developed within each turn of the wheel can be color coded. The size of the balls that represent the constellation stages are linked to their 'degree of influencing' of the overall system (i.e. the most powerful, regime, is represented with the biggest size ball). Hence, the wheel, together with the picture of the constellation maturation stage and trajectory, provide a visual and effective set of indicators to track progress and plan for future actions.

In the case study presented in sections 3 and 4, strengths developed are identified by naming actions undertaken within each activity, and expert judgment determines whether the strength has been developed lightly or strongly, as well as determining the SuDS 'landed rocket' maturation stages and trajectory. The alignment with the established regime is conducted by examining enablers and obstacles for each type of institutional work presented in Ferguson et al. (in press). Future research could lead to a parametric analysis being proposed for this examination. Furthermore, while we focus on the institutional work required depending on the constellation's alignment with the established regime, the methodology itself leaves the door open to embrace in the future additional tools and methods.

For simplicity, throughout the rest of this article we use the word SuDS to refer to the SuDS 'landed rocket' concept.

3. Urban stormwater management in Benaguasil: the journey.

The methodology presented has been applied to the journey of Benaguasil, a Mediterranean city, towards a regenerative built environment. With a mild and semi-arid climate, Benaguasil has an average annual rainfall of 432 mm, with very strong seasonality. As many Mediterranean cities, it experiences very high peak rainfall intensities that concentrate in short periods of time, which together with city characteristics such as high population density (4 750 hab/km^2 in Benaguasil) and large impermeability, difficult urban stormwater management.

This section presents a longitudinal narrative of the case study research, establishing three key transitions states: historical, current and future (Brown et al., 2009; Duffy and Jefferies, 2011). The analysis of whether the actions undertaken have influenced the desired change and to what extent is presented in section 4.

The focus of the narrative and the consequent analysis is in the current state, which comprises activities that although not yet completed are well defined and planned. In-depth detail is given to the interplay between frontrunners and the institutions.

3.1. The 'place' and its historical relationship with water (ancient times to 2008)

Located 20 km inland from the city of Valencia (in the western Mediterranean on the Spanish coast) and currently counting with over 11 000 inhabitants, Benaguasil has appreciated the value of water from ancient times, being essential for its agricultural based economy (Grau, 1995). Research by Nicolau (1990) brings to light documents from XIV-XIX centuries that reveal Benaguasil strong relationship with water: the main water supply source was the Turia river, from which water was gravity-transported using irrigation channels for drinking, housing and agricultural use, being as well the energy source for the flour mills. During rainy periods, when the river water turbidity was high, drinking water used to be manually extracted from few wells located in the 'villa', and cisterns were used to provide fresh water in summer periods.

Nowadays the town faces three major problems in terms of urban water management: frequent pluvial flooding and backup flows from overloaded combined sewers into dwellings, pollution of water courses from CSOs and high energy consumption. Believing that the solution could not come only from increasing the capacity of conveyance and treatment facilities, the Municipality of Benaguasil started to think ‘out of the box’, understanding that a more natural approach and raking up traditional practices might be needed.

3.2. Transitioning towards a regenerative urban stormwater management (2008-2015 and beyond)

Since 2008, Municipality of Benaguasil has been involved in several research projects at European level, looking for an alternative regenerative approach to traditional stormwater practice. Table 1 shows the chronology of the projects in which AQUAVAL and E^{2}STORMED are the cornerstone projects, while the involvement in the SUFRI project and the PiP program built up on the efforts to achieve the desired transition.

ACRONYM	FULL TITLE	PERIOD	FUNDING PROGRAMME	BENAGUASIL INVOLVEMENT	MAIN CONTRIBUTION TO THE JOURNEY	WEBSITE
SUFRI	Sustainable Strategies of Urban Flood Risk management with non-structural measures to cope with the residual risk	2009-2011	2nd ERA-Net CRUE Funding Initiative	Case study city	Building relationships with university and awareness of the need of a multidisciplinary team to tackled a problem (pluvial flooding)	www.sufri.tugraz.at
AQUAVAL	Sustainable Urban Stormwater Management Plans, promoting SUDS and considering Climate Change, in the Province of Valencia	2010-2013	EU LIFE+2008 Community Initiative (European Regional Development Fund)	Partner (1 of 5)	Putting pilots in the ground and monitoring their performance	www.aquavalproject.eu
PIP	Pioneers into Practice	2012-2014[a]	European Institute of Innovation and Technology (EIT)	Host institution	Capacity building with pioneers with diverse background from the region and other European countries	www.climate-kic.org/pioneers
E^{2}STORMED	Improvement of energy efficiency in the water cycle by the use of innovative storm water management in smart Mediterranean cities	2013-2015	EU MED Program (European Regional Development Fund)	Partner (1 of 9)	Applying the transition framework and capacity building with regional institutions	www.e2stormed.eu

[a] Discontinuous involvement, 5 months in total.

Table 1. *Stormwater related European projects in which Benaguasil has been involved.*

The narrative focuses on detailing the actor dynamics and the institutional work that is taking place in this phase, whereas the more technical aspects of the experiments are briefly mentioned. The main activities related to Benaguasil are shown in Table 2, which follows the activity classification of the Sustainable Transition Management Cycle.

SUSTAINABLE TRANSITION MANAGEMENT CYCLE[a] LEVEL	TYPE OF ACTIVITY	2008-2009	2010	2011	2012	2013	2014[b]	2014 – 2015[c]
STRATEGIC	1. Develop the Transition Arena	[A] Partnership formed for project proposal	[A] RWG formation		[E] Partnership formed for project proposal	[E] RWG formation		
STRATEGIC	2. Organize/ Facilitate stakeholders		[A] 1st RWG meeting	[A] 2nd RWG meeting	[S] Emergency management group meeting	[E] 1st and 2nd RWG meetings	[E] 3rd RWG meeting	[E] 4th to 6th RWG meetings
TACTICAL	3. Identify Problems and Issues	[A] USWM problems identified by specialist	[S] Pluvial flooding identified by local stakeholders and university specialists	[S] Pluvial flooding risk assessment by specialists and results accepted as realistic by Local Council's representatives	[E] USWM problems identified at project proposal stage by urban drainage specialists	[E] USWM problems identified, discussed and agreed by RWG members		[E] USWM problems further discussed during RWG meetings as required
TACTICAL	4. Develop the Long Term Integrated Vision	[A] Local political will to improve USWM					[E] Vision under discussion with the RWG	[E] Vision to be agreed within the RWG
OPERATIONAL	5. Develop the Transition Agenda					[A] Development of the Benaguasil Sustainable USWM Plan (Draft)		[E] Development of the Strategic Action Plan and discussed at 5th and 6th RWG meeting
OPERATIONAL	6. Transition Experiments		[A] Decision on 3 demonstration SuDS location and typology	[A] Detailed design of 3 SuDS pilot sites [O] Construction of permeable parking	[A] Construction of 3 SuDS pilot sites [A] Monitoring of the 3 SuDS pilot sites and the permeable parking starts	[A] the 1 year monitoring of the 4 SuDS pilot sites ends [E] Sites selection for testing the DST and retrofitting a green roof [E] Energy monitoring of building to be retrofitted with a green roof	[E] Application of the Draft DST [E] Construction of the retrofitted green roof [E] Energy and water green roof site monitoring	[E] Application of the Final DST [E] Interpretation of the green roof site monitoring results
OPERATIONAL	7. Identify Responsible Parties / Engage the community		[A] Citizens invited to the project kick-off meeting	[S] Opinion poll on flood risk awareness of the population concerned [A] Citizens invited to the permeable parking opening ceremony		[A] Local schoolchildren learn about USWM and visit the SuDS pilot sites		[E] Identification of broader stakeholders (4th RWG) and their engagement (5th RWG) [E] Regional conference for local councils [E] Guided tour on SuDS and historic USWM features for the local community
TACTICAL	8. Process Documentation and Capacity Building		[S] Compilation of information on past flooding events [A] Progress Reports, meetings minutes and Dissemination	[S] Project partners visit Benaguasil and learn about the AQUAVAL project [A] Progress Reports, meeting minutes and Dissemination [A] RWG visit the permeable pavement parking lot	[S] Development and approval of the Action Plan against Flood Risk [A] Progress Reports, meeting minutes and Dissemination [P] Regional pioneer involved in USWM	[A] Development of the Benaguasil Sustainable USWM Ordinances (Draft) [A], [E] Progress Reports, meeting minutes and Dissemination [E] Project partners and RWG visit SuDS pilot sites [P] Regional and international pioneer involved in USWM	[E] RWG members learn about the demonstration SuDS monitoring results [E] Progress Reports, meeting minutes and Dissemination	[E] Meetings minutes and Dissemination [E] RWG members learn about the green roof monitoring results [P] Regional and international pioneer involved in USWM
TACTICAL	9. Evaluation and Learning				[A] Reflection on the AQUAVAL project progress to date from a transition perspective	[A] Analysis of the monitoring results		[E] Analysis of the monitoring results [E] Reflection on the E²STORMED project
STRATEGIC	10. Next Round of Transitioning and Visioning				[E] Development of E²STORMED project proposal			[E] Reflection on ways to continue the work as a group during the 6th RWG

[a] From (Duffy and Jefferies, 2011); [b] Until end of April 2014; [c] From May 2014 until end of June 2015 (as per the approved project schedule)
Legend: Identification of the project to which each activity is related as follows: [S]: SUFRI; [A]:AQUAVAL; [E]: E2STORMED; [P]: PIP; [O]: Other activities outside the previous projects
Acronyms: DST: Decision Support Tool; SuDS: Sustainable Drainage Systems; RWG: Regional Working Group

Table 2. *Main activities undertaken during the stormwater related research European projects in which Benaguasil has been involved.*

3.2.1. Building the bridge

The importance of individual frontrunners seen in the literature (Smith, 2007; Brown et al., 2013) is confirmed in this case study. In 2008, the first author of this article envisaged the opportunity to form a consortium in the Valencian Region of Spain to apply for European funding, in order to promote this innovative approach which was little understood in the country at that moment (Castro-Fresno et al., 2013; Perales and Andrés, 2008).

The partnership comprised two municipalities in the region (Xàtiva and Benaguasil), the frontrunner's consultancy firm, a UK University as an international expert on SuDS and a regional public entity that deals with EU relationships in the role of 'communication partner'. It counted with Diputació de València (county council) as co-financer for the construction of the proposed pilot SuDS sites. The project was approved for European Regional Development Fund (ERDF) co-financing and started in January 2010.

The inclusion of the Municipality of Benaguasil in AQUAVAL started its relationship with the 'ignition' frontrunner, who is linked to Universitat Politècnica de València (UPV). This link to the university located in the same region promoted the town to be one of the case studies for the pilot application of the SUFRI methodologies (Escuder-Bueno et al., 2011), highlighting the difficulty for local authorities to develop Municipal Action Plans against Flood Risk. UPV offered and agreed with Benaguasil Council's representatives, to develop such a Plan for the town as an additional task to the project. Following numerous meetings and conversations with local and regional stakeholders (local police, works' brigade, etc.) the Municipal Action Plan against Flood Risk for Benaguasil was approved by the Local Council in 2012, being the first Plan to be approved in the Region of Valencia under the current legislation.

3.2.2. Crossing the bridge

The guiding principle of AQUAVAL was to "make the best use of municipalities' landscape and morphology in order to integrate water infrastructure using SuDS, adding social and environmental values" (Perales-Momparler et al., 2013).

Three inner-city areas were selected and retrofitted to accommodate run-off from nearby surfaces, decreasing the flow rate and volume of stormwater that enters the combined sewer networks (frequently causing CSOs) or freely flows through the streets (occasionally flooding dwellings). The selection process (Casal-Campos et al., 2012) took 7 months, during which the responsible municipal councilor, the local technical architect and the regional SuDS expert meet 5 times, 2 of them also involving the international partner. Local stakeholders gained knowledge on this innovative stormwater management approach during the process, which led them to propose changing the projected impermeable car park of the new municipal swimming pool for a permeable one within the same budget. This car park was the first pilot constructed in Benaguasil using the new approach (increasing the number of pilots to four).

The four SuDS schemes were equipped with suitable instrumentation, and monitored for a year both in terms of runoff quantity and quality (Millán et al., 2013; Perales-Momparler et al., 2014).

Being the SuDS demonstration sites the core of the AQUAVAL project, additional groups of activities were undertaken (Table 2), including the creation and coordination of a RWG involving in the project actors from across the region in the water sector, public and private (with a high representation of design professions, e.g. architects and engineers, and the economic sector). The status of the 'communication partner', a regional public entity that deals with EU relationships, was essential in the successful response of the actors to the call to form the RWG, not only for the number of attendees (Table 3), but for the political and managerial representativeness, which attracted the attention of the media, with the opening ceremony of the public indoor swimming pool permeable car park (2nd RWG meeting) being broadcasted by the regional TV at premium midday news program.

	No transition framework in place						Transition framework in place					
	1st A-RWG: Nov 2010		2nd A-RWG: Jun 2011		1st S-EWG: Jun 2012		1st E-RWG: Apr 2013		2nd E-RWG: Nov 2013		3rd E-RWG: Apr 2014	
Type of Institutions:	Nº of Institutions	Nº of Participants	Nº of Institutions	Nº of Participants	Nº of Institutions	Nº of Participants	Nº of Institutions	Nº of Participants	Nº of Institutions	Nº of Participants	Nº of Institutions	Nº of Participants
Regional public authority	4	6	2	3	1	1	6	7	5	5	3	3
Local public authority	2	7	2	7	2	8	1	5	1	2	1	2
Academia	1	2	2	2	1	1	1	2	1	2	1	3
Non-profit / government related organizations	3	5	2	4	-	-	-	-	-	-	2	2
Economic and professional associations/entities	5	6	5	7	-	-	-	-	-	-	-	-
Private sector	1	2	2	3	1	1	2	3	2	3	2	3
Civil society, community groups	-	-	-	-	-	-	-	-	-	-	-	-
The media	1	2	3	5	-	-	1	1	1	1	-	-
EU admon-technical representative	-	-	1	1	-	-	-	-	-	-	-	-
TOTAL	17	30	19	32	5	11	11	18	10	13	9	13
Level of participation of non-project-linked actors	Low		Low		Medium		Low		Low-Medium		Medium	
Major success	Political and managerial representativeness		Attracted the attention of the media		Main local and regional stakeholders in the field of emergency management represented		Relevant environment, water, energy, planning authorities represented		Interest and commitment of RWG members		Keeping the commitment of the RWG members, with absences formally justified and interested on meeting outcomes	
Room for improvement	Too many actors, whereas River Basin Authority was not present		Too many actors, whereas River Basin Authority was not present		Continuity of the group		Level of participation of non-project-linked actors		Need for further explanation of transition framework and methods		More time required to discuss the vision	

LEGEND: A-RWG: Regional working group in the frame of the AQUAVAL project; S-EWG: Emergency working group in the frame of the SUFRI project; E-RWG: Regional working group in the frame of the E^{2}STORMED project

Table 3. *Participation of stakeholders in meetings.*

Despite the interest roused, this RWG only met twice at the first part of the project due to the fact that the 'communication partner' had to abandon the project in December 2011 and was not replaced.

3.2.3. On the road

In April 2012, the authors and the Municipality of Benaguasil envisaged that boosting this regenerative sustainability approach within the town and up-scaling and influencing standard practices would "require a programmatic rather than a single project-based approach" (McCormick et al., 2013). With this idea, and the will to extend this approach to other Mediterranean regions and link water management to other sectors such as energy, the E^{2}STORMED project was born, approved for co-financing from the ERDF, and started in January 2013. It addresses the challenge of improving energy efficiency in the urban water cycle in Mediterranean cities by the use of innovative stormwater management systems. With 6 operational partners (local authorities) in charge of the implementation in their cities of the management tools developed by the two academic partners, it became feasible to verify the applicability of the theoretical practical tool and to demonstrate its real value for the municipalities (Escuder-Bueno et al., 2013).

In the case of Benaguasil, the most significant effort was at the beginning of the project in selecting the actors to form part of the E^{2}STORMED RWG. The objective was to form a reasonable size group that allowed for a productive dialog, formed by key local and regional entities in urban planning, water and energy sectors, represented by a mixture of political, technical and managerial background actors. They would form the basis, the 'core' group, bringing in other stakeholders at different stages of the journey as considered appropriate. Due to the lack of strong community associations, citizens are not formally represented in the RWG at this moment, although their interests and needs are constantly taken into account (due to the relatively small size of the town, politicians are close to the citizens).

This time the General Directorate of European Projects and Funds in the Valencian Region convened the selected actors and successfully hosted the first meeting, after which two additional ones have followed until May 2014 with a considerably constant number of attendees (Table 3).

To date (May 2014), in addition to cultural-cognitive institutional work on SuDS (putting in value results for the AQUAVAL monitoring campaign) and transition management, activities have focused on the identification of the problems faced by Benaguasil (frequent pluvial flooding, CSOs and high energy consumption) and the objectives that the strategy shall pursue (as an initial step of the visioning exercise). These objectives are (as per agreed on 2nd RWG): reducing CSOs; protection of receiving water bodies; reducing energy consumption in the urban water management; landscaping integration of infrastructures; aquifer recharge; optimization of drinking water use.

E^{2}STORMED experiment activities consist of the selection of two areas within the city (an urban area that could be retrofitted and a future urban expansion) and the application of the Decision Support Tool (DST) developed by universities (Escuder-Bueno et al., 2013) to compare two different drainage scenarios in each area (one with conventional drainage infrastructure and one with the SuDS regenerative approach). In addition, a green roof has been retrofitted in a public building in Benaguasil, and its effects in energetic and hydraulic terms are being monitored.

The fourth European program involving Benaguasil is 'Pioneers into Practice' (PiP) (Table 1), hosting regional and international professionals/PhD students committed to tackle the climate change challenge. Pioneers are assigned sustainability-related work tasks during their 4-week placements (i.e. involvement in Benaguasil green roof design and monitoring), which turns on more professionals being aware of, and gaining experience on, regenerative stormwater management practices in the region and abroad.

It is worth mentioning that Benaguasil project activities are being echoed by RWG members using their own channels. Achievements at regional and international level with the AQUAVAL project are effective empowerment tool and fuel frontrunners expectations: selected as an example of good practice at European level (Progress Consulting S.r.l. and Living Prospects Ltd., 2011); nominated as finalist for the Novatech Awards, in the "City or catchment scale strategies" category (www.novatech.graie.org); and most important, included as example of the new indication to promote the use of SuDS in all urban areas of the Valencian Region added in the revision (under approval process) of the regional plan for flooding prevention (Resolution of 31st October 2013).

Elicit a consensus vision for Benaguasil desirable future will be the main goal of the remaining RWG meetings, which is expected to be inspired on the regenerative USWM framework (Fig. 2) and visioning exercises from the literature (de Haan et al., 2014). This vision will be shaped by interactive backasting (Næss & Vogel, 2012; Quist et al., 2011) coupled with the development of Benaguasil Strategic Action Plan (Ferguson et al., 2013b; Truffer et al., 2010) for enabling the transition towards a regenerative stormwater management, taking as a starting point the draft Benaguasil Sustainable USWM Plan developed during AQUAVAL.

3.2.4. Looking ahead

It is the interest of the Municipality of Benaguasil to keep steering the wheel, learning from the past and preparing the next round of transition. Coalitions and collaboration between the RWG current members could make it possible, while aiming for a closer involvement of the regional productive fabric, with new work niches (i.e. specialists in green roof and other vegetated SuDS construction and maintenance) but also with the adaptation of more traditional sectors (i.e. ceramic and concrete) in the search for new products applicable to the regenerative approach.

4. Analyzing the journey to date and envisioning the future

The application of the proposed methodology to Benaguasil is an example of how it can be used even when the journey started prior to explicitly formalizing the desired paradigm and the visioning for USWM (Tiers 1 and 2). We identified that one cycle of Tier 3 had occurred before Tiers 1 and 2 where defined. Afterwards, in Tier 3 a second turn takes place, with more envisaged to follow.

The methodology, as applied in this case study: a) reconnects human aspirations and activities with the evolution of natural systems; b) brings a new way of thinking about how stormwater is managed in the built urban environment, c) gives the role of 'gardeners in and of place' to practitioners decision makers; and, d) works developmentally (taking systems to the next level), which according to Mang and Reed (2012), are the premises of a regenerative methodology.

SuDS mimic natural hydrology in urban environments while providing healthier and more livable cities. This methodology links stormwater management with other systems such as energy, and acknowledges that the SuDS approach needs to be integrated with a wide range of other strategies (Charlesworth, 2010). It highlights the relevancy of stakeholder involvement (Brown et al., 2013) and reconnects to the essence of place (which in the case of Benaguasil includes 'raking up' traditional practices like rainwater harvesting), enabling its regeneration and evolution (du Plessis, 2012) in a stepped and cyclical manner.

Data collection was conducted by the authors, directly involved in the process from the beginning. Afterwards, the longitudinal narrative presented in Section 3 was shared and agreed by Benaguasil council representatives. The analysis conducted herein by the authors follows opinions gathered from group interviews with 20 main actors of the RWG and 8 responses to a structured questionnaire.

4.1. Advancing innovations by steering the wheel

According to Nevens et al. (2013), "applying transition management in a city policy environment is a transition in itself", and that it is the main differential factor of the two turns of the wheel that we identify in Benaguasil transition to date (Fig. 6).

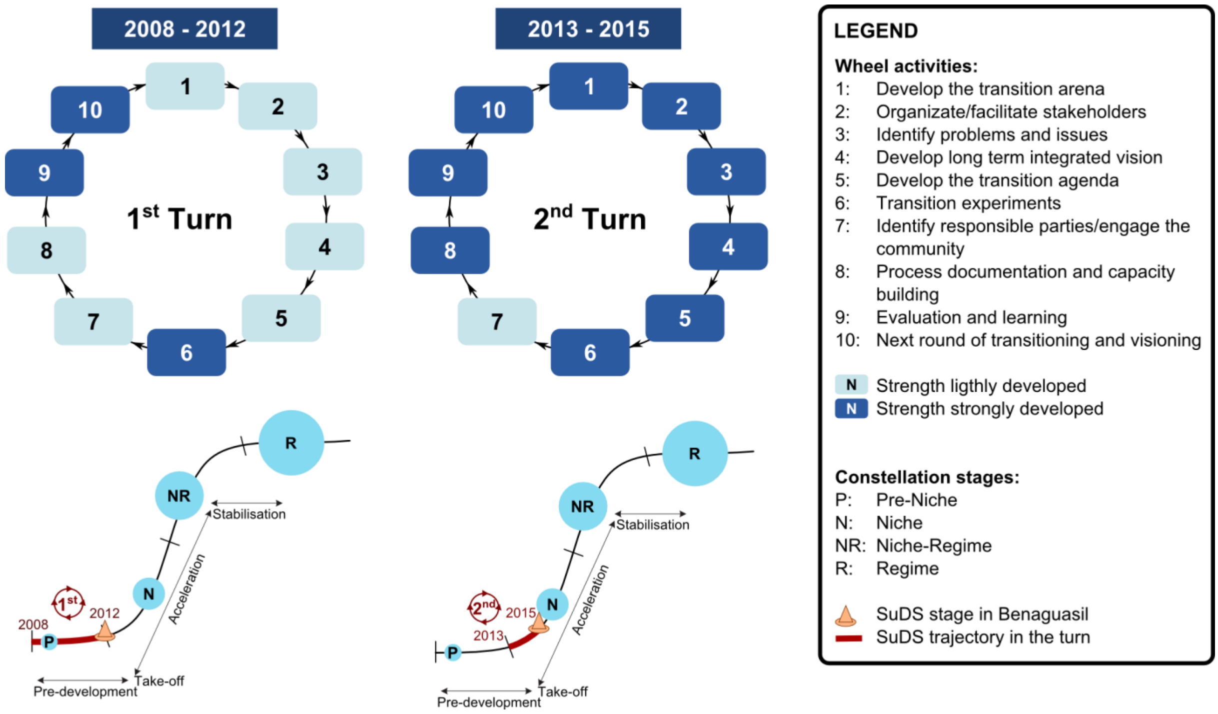


Fig. 6: *Set of indicators: identification of the strengths developed (upper part) and SuDS maturation stage and trajectory (lower part) of Benaguasil journey towards a regenerative USWM.*

By analyzing the activities presented in Table 2, we conclude that by the end of the E^{2}STORMED project (June 2015) Benaguasil will have completed 2 turns of the wheel towards the desired regenerative USWM, having developed strengths in all activity types in different intensity during the process. Whereas in the first turn we consider that SuDS (an innovative approach with no influence in USWM practices at the beginning of the process) attained the niche stage in Benaguasil, progression on the acceleration section of the maturation curve is slow despite the application of transition management. This was predictable by looking at the steepness with which transition scholars have pictured this transition phase over the years.

As illustrated in Fig. 6, the methodology that we propose provides a visual and effective set of indicators of strengths developed and SuDS maturation stages and trajectory progress achieved in Benaguasil in each cycle, highly important for understanding a multi-level and multi-dimensional process of change in which to base transition management interventions upon (Brown et al., 2013).

4.2. Role played by actors and institutions

The main result of the analysis of this case study, in line with other experiences in the literature (Brown et al., 2013; Loorbach and Rotmans, 2010), is the relevant role of the actors involved in the process. While the partners of the AQUAVAL project, through hard work and constant local political support in Benaguasil, were able to achieve the niche stage for the SuDS innovative approach, progression beyond that point was only marginally achieved (e.g. indication to promote the use of SuDS in all urban areas of the Valencian Region in regional legislation), although relevant.

Back-analyzing that first turn of the wheel, we think that the project partnership had a good balance of regional actors (two local authorities, one local SuDS expert firm, one strong communication partner and an overseas expert with an academic background), which strength was reinforced with the involvement of the 'close by' university (UPV) in monitoring and analyzing the SuDS pilot sites. However, the composition of the RWG was not thoroughly discussed, ending up being a too large group (with a high representation of design professions and the economic sector) who did not have a clear role in the process, whereas other potentially relevant actors were not present (e.g. River Basin Authority).

Reflection on the above led to the identification of the need for a methodology that could guide the process towards the desired regenerative urban built environment, in particular, in terms of selecting the actors with whom to continue the journey. Insights from the SWITCH project and partner cities experiences (Jefferies and Duffy, 2011) were crucial to deciding which RWG members should steer the wheel. However, deciding the composition of a stakeholders group is not straightforward (Reed et al., 2009). The main difference in this second turn is that actors involved are aware that they are actually steering the wheel, and a methodology is in place to guide them, without relinquishing their power and duty of decision-making.

The fact that there are five additional Mediterranean cities in the E^{2}STORMED project that are also steering their wheels, gives Benaguasil a platform to shear experiences with and learn from (with the valuable support of the two universities), while the well thought composition of the RWG (local and regional entities in urban planning, water and energy sectors, represented by a mixture of political, technical and managerial background actors), provides a clear role for each frontrunner. This 'core' group will be the one deciding what additional stakeholders need to be brought into at different stages of the journey, as considered appropriate. In the near future, it is scheduled that the identification of which broader stakeholders to involve in this second turn of the wheel takes place during the 4th RWG, engaging them for the 5th RWG (although it is expected to hold part of the meeting with only the 'core' actors present). By engaging the remaining stakeholders (social scientists, ecologists, economists, design professions, public health experts, business institutions, civil society, community groups, the media) as required in this last part of the E^{2}STORMED project, the 'core' RWG members can disseminate the project results as a common achievement, at the same time that with a shared vision, start to define what could be the role of the other actors in the next turn of the wheel.

While there have been activities for the local community and they are plan to continue (e.g. guided tour around SuDS pilot sites and historical water features, such as water mills and irrigation channels), we envisage that citizens will have a more relevant role to play in the future third turn of the wheel. Their stronger involvement would also provide robustness to the journey, as at the moment, and despite the active involvement of technical municipal staff, the process is highly political steered, and electoral changes or political decision at local and regional levels could change the course of the transition (e.g. as was the case when the 'communication partner' abandoned the AQUAVAL project and that RWG did not meet again).

4.3. Requirement for further institutional work

Table 4 summarizes barriers and enablers that characterize the transition towards a regenerative USWM in Benaguasil. From the information in this table, the SuDS approach can be identified as 'disrupting' the established regime at the three institution types: cultural-cognitive, normative and regulative (i.e., need for new technical knowledge about SuDS, need to integrate ecologists, urban planners, landscape architects, etc. in communities of practices and need for private landowners to engage in providing source stormwater management).

Hence, supporting the SuDS approach maturation from niche to niche-regime will require further actions in all institutional work types (cultural-cognitive, normative and regulative) according to the hypotheses of Ferguson et al. (in press), which are aligned with the Benaguasil experience to date:

- *First turn of the wheel*: relating the potential benefits of SuDS (water quantity, water quality, amenity, biodiversity, link to the place) with impacts of landscape pressure (flooding, contamination of water courses, impacts of climate change) has allowed progression form pre-niche to niche, carrying mainly cultural-cognitive institutional work (e.g. dissemination of scientific knowledge; technology testing with practical experience on design and maintenance; gathering of empirical data from experiments that confirms

SuDS benefits at the same time that provides learning experience for future applications). In addition, some preliminary (not completed) work was undertaken in the normative (e.g. informal networks; draft Benaguasil Sustainable USWM Plan) and regulative (e.g. draft local ordinances for USWM) types of institutional work.

- *Second turn of the wheel*: progress has been achieved by reinforcing the cultural-cognitive type of work (e.g. developing and testing the tool for decision makers; dissemination of pilot SuDS monitoring results to a broader audience, including a regional conference for local councils) while focusing on normative work (e.g. bringing together key regional actors that, with a holistic view, shear visions and concerns, and work together to build a strategic program, with coordinated and co-supported actions, towards the achievement of common goals), something that we consider essential for the regulative mechanisms (e.g. municipal USWM ordinance) to be successful.

- *Third turn of the wheel*: we agree that further institutional work of all three types is required to mature the SuDS innovation towards a regenerative urban built environment. In particular, dissemination of results from the newly-installed green roof (cultural-cognitive), the commitment of regional institutions to implement the activities included in the Benaguasil Sustainable USWM Plan and the regular use of the DST (normative), and the approval of the municipal USWM ordinance (regulative), are envisaged to be key steps in the next turn of the wheel.

Institutional Work[a]		Barriers typology[b]	Benaguasil after 2nd turn of the wheel	
Types	Indicators		ENABLERS	OBSTACLES
Cultural-cognitive	Cultural knowledge		- Local politicians and technicians with some knowledge on Sustainable Drainage Systems (SuDS) approach	- Urban stormwater considered a waste product that shall be evacuated as rapid as possible out of site, without considering the consequences downstream
	Technical knowledge	Lack of information, knowledge and understanding in applying integrated, adaptive forms of management	- Local technicians with deeper knowledge on SuDS design - Academia, regional frontrunners and local press disseminating pilot SuDS results	- Lack of SuDS technical knowledge of regional practitioners (design teams) and construction companies. Experience on piped networks
	Experiential knowledge	Little or no monitoring and evaluation	- Local and regional niche actors with some knowledge on SuDS performance and energy implications - Pilot sites on the ground and monitored	- Lack of a broad knowledge and experience of municipal workforce on how to maintain and operate SuDS.
	Implementation tools		- Local and regional niche actors with some knowledge on the Decision Support Tool developed within the E^{2}STORMED project	- Lack of SuDS guidelines/manuals at local and national level. Manuals principally based on conventional Urban Stormwater Management (USWM)
Normative	Public expectations	Poor communication	- SuDS approach communicated to citizens by local press and by arranging guided visits to pilot sites	- The general public do not relate USWM with river water quality or availability of green space
	Communities of practice	Limited community engagement, empowerment & participation	- Organization and facilitation of USWM stakeholders in the Regional Working Group (RWG)	- Usual practice is that USWM be dealt by engineers once the site layout has been decided by planners and architects, without considering the SuDS approach
	Roles and responsibilities	Unclear, fragmented roles & responsibilities		- USWM is the municipalities' responsibility, but restrictions to discharges into the water public domain (national governed) unclear - No implication of private landowners in USWM
	Goals and commitments	Poor organizational commitment No long-term vision, strategy Lack of political & public will	- Niche regional actors (planning-water-energy) actively involved in the RWG - Local political support to SuDS approach and willing to continue steering the wheel - Municipal technicians involved in visioning and strategic planning	 - Urban stormwater considered a waste product - Technical decisions generally politically influenced
	Standards	Technocratic path dependencies	- Case study selected for the Novatech Award 2013	- Incremental improvement of conventional USWM considered best practice (e.g. big underground detention tanks to prevent CSOs), with design standards and guidelines including them
Regulative	Governance arrangements	Uncoordinated institutional framework		- USWM provided by the municipality but not revenue collected by beneficiaries - No implication of private landowners in USWM
	Resources mobilization	Insufficient resources (capital and human)	- Co-financing received from EU and a regional authority - Recent national legislation opens the door to co-finance urban interventions that fall under the SuDS approach (e.g. green roofs) (R.D.233/2013)	- USWM investment from non-specific local budget lines (usually financed by regional, national or European funding programs)
	Regulatory mechanisms	Limits of regulatory framework	- Recent national legislation highlights the need to take stormwater out of sewers (R.D.1290/2012) - Regional legislation (draft) promotes the use of SuDS in urban areas (CITMA, 2013) - Benaguasil USWM ordinance (draft) developed	- USWM unregulated at local level and restrictions to discharges into the water public domain (national governed) unclear

[a] As per (Ferguson et al., 2014)
[b] As per (Brown and Farrelly, 2009). Classification by authors (it is acknowledge than to overcome those barriers work needs to be done in more than one category.

***Table 4:** Barriers and enablers in Benaguasil transition towards a regenerative USWM.*

The journey of Benaguasil also confirms that the acceleration section of the road is much steeper that the pre-development one, as the more a disrupting innovation approaches the regime, the more barriers need to be addressed. Progress is slower, but possible with the support of a methodology as presented in this article.

4.4. Envisioning the future

We believe that in Benaguasil the seed is there to enable, shape and speed up the desired transition towards a regenerative USWM that evens the path for other Mediterranean cities to follow. As concluded by Brown et al. (2013), to influence the regime, the bridging function of the RWG, needs to "first focus on generating understanding, collating evidence and nurturing relationships, then build confidence amongst practitioners, up-skill and train a broad range of actors within the sector, then focus pressure towards generating policy shifts". The Benaguasil case study can contribute, together with other experiences rolled out in a city context (Nevens et al., 2013), to 'prove' whether transition management 'works', bringing the particularity that transition had started before the frontrunners were conscious of 'steering the wheel'. Despite all of the above, a successful transition is not guaranteed (Geels and Schot, 2007; Smith, 2007).

The transition in Benaguasil would benefit from testing emerging regenerative design frameworks (e.g. Plaut et al., 2012) in one of the planned new developments. It would be ideal for putting into practice concepts such as the place-based approach, which in terms of stormwater management could include reinforcing the role of the existing water mills and irrigation channels, and recovering the rainwater harvesting tradition. Including educational signs that guide the visitor along the tangible regenerative elements but also that tell the story of how a trans-disciplinary team was involved in the design process, during which "the role of the architect/planner/designer [shifted] to that of facilitator of a process of revealing, rather than acting as master mind" (du Plessis, 2012), would make it a place where one is proud to live. This proposed case study would bring light on how the notion of 'place' might accommodate densely urban settings, as 'stories of place' presented in the literature are almost exclusively non-urban (Cole, 2012a).

"How to measure and evaluate progress is a major aspect of bringing about sustainability in urban contexts" (McCormick et al., 2013), and acknowledging that the set of indicators that we have used in this case study has room for further testing and improvement, its applicability on tracking the progress made by the case study city represents an important step in the field.

Carefully observing the evolution of this case study, in particular the role of institutions and their dynamics, would bring light into research needs identified by others in the field (Nevens et al., 2013).

5. Conclusions

This paper presents an innovative methodology for approaching the regenerative urban built environment concept focusing on municipal infrastructure systems or sub-systems (in this case stormwater management) with a holistic view.

Building upon literature and practice that supports a flexible approach to stormwater management in urban environments that mimic natural processes and predevelopment hydrology (SuDS) as one way to, amongst others, help to prevent and adapt to climate change, we highlight the relevance of the connection to the place for adoption of best practices that conduct towards a regenerative system. We incorporate it to the SuDS representation, naming it the SuDS 'landed rocket'.

The approach used in the Benaguasil journey towards a regenerative built environment can enlighten the path of other urban areas that share the same goal/vision but only see obstacles in their path. This urban scale case study located in the Mediterranean shows how, by focusing in one part of the complex system, while keeping a holistic approach, it is possible to make progress in only few years and have a promising future ahead.

To overcome the barriers that drag out progress, we identify two main enablers: a) A structured set of activities, the 'wheel', to guide and document the process, which is steered by a group of regional actors, the RWG, with a trans-disciplinary approach for systems-thinking, that starts with a stable small group of public policy and the academia actors, and with a shared vision grows to involve the remaining stakeholders as required (social scientists, ecologists, economists, design professions, public health experts, business institutions, civil society, community groups, the media); b) a visual and effective set of indicators, the wheel and the constellation (the SuDS 'landed rocket') maturation stage and trajectory, that monitors and assesses the progress achieved and identifies the strategies to move forward.

Integrating the views and strategies from actors at different but interconnected scales (from river basin down to individual buildings), following a structured but flexible methodology, opportunity emerges to combine efforts that catalyze the switch towards an urban built environment that supports a genuinely sustainable society.

Acknowledgements

This research has been conducted as part of the Life+ program project "AQUAVAL: Sustainable Urban Water Management Plans, promoting SUDS and considering climate change, in the province of Valencia" (Life08ENV/E/000099) and the MED program project "E2STORMED: Improvement of energy efficiency in the water cycle by the use of innovative storm water management in smart Mediterranean cities" (1C-MED12-14), both supported by ERDF funding of the European Union.

The authors would like to thank Prof. Chris Jefferies for his guidance throughout the projects and proof-reading of this article.

References

Agudelo-Vera, C.M., Mels, A.R., Keesman, K.J., Rijnaarts, H.H.M. 2011. Resource management as a key factor for sustainable urban planning. J. Environ. Manage., 92, 10, 2295-2303. http://dx.doi.org/10.1016/j.jenvman.2011.05.016

Andrés-Doménech, I., Múnera, J.C., Francés, F., Marco, J.B., 2010. Coupling urban event-based and catchment continuous modelling for combined sewer overflow river impact assessment. Hydrol. Earth Syst. Sci., 14, 2057–2072. http://dx.doi.org/10.5194/hess-14-2057-2010.

Apostolaki, S., Jefferies, C., Wild, T., 2006. The social impacts of stormwater management techniques. Water Pract. Technol., 1, 1. http://dx.doi.org/10.2166/WPT.2006009

Arnbjerg-Nielsen, K., Willems, P., Olsson, J., Beecham, S., Pathirana, A., Bülow G., I., Madsen, H., Nguyen, V.T.V., 2013. Impacts of climate change on rainfall extremes and urban drainage systems: a review. Water Sci. Technol., 68, 1, 16-28.

Bastien, N., Arthur, S., Wallis, S., Scholz, M., 2010. The best management of SuDS treatment trains: a holistic approach. Water Sci. Technol., 61, 1, 263-272. http://dx.doi.org/10.2166/wst.2010.806

Biddulph, M., 2011. Urban design, regeneration and the entrepreneurial city. Progress in Planning, 76, 2, 63-103. http://dx.doi.org/10.1016/j.progress.2011.08.001

Binney, P., Donald, A., Elmer, V. Ewert, J., Phillis, O., Skinner R., Young, R., 2010. IWA Cities of the Future Program. Spatial Planning and Institutional Reform Discussion Paper for the World Water Congress. Spatial Planning and Institutional Reform Working Group Report, Montreal, Canada. Last accessed 21-May-2014 from http://www.iwahq.org/contentsuite/upload/iwa/document/updated%20iwa%20spatial%20planning%20and%20institutional%20reform%20group%20montreal%20discussion%20paper.pdf

Brown, R.R., 2005. Impediments to Integrated Urban Stormwater Management: The Need for Institutional Reform. Environmental Management, 36, 3, 455-468. http://dx.doi.org/10.1007/s00267-004-0217-4

Brown, R.R., Farrelly, M.A., 2009. Delivering sustainable urban water management: a review of the hurdles we face. Water Sci. Technol. 59, 5, 839-846. http://dx.doi.org/10.2166/wst.2009.028

Brown, R.R., Keath, N., Wong, T.H.F., 2009. Urban water management in cities: historical, current and future regimes. Water Sci. Technol. 59, 5, 847-855. http://dx.doi.org/10.2166/wst.2009.029

Brown, R.R., Farrelly, M.A., Loorbach, D.A., 2013. Actors working the institutions in sustainability transitions: The case of Melbourne's stormwater management. Global Environmental Change, 23, 4, 701-718. http://dx.doi.org/10.1016/j.gloenvcha.2013.02.013

Campbell, N., D'Arcy, B., Frost, A., Novotny, V., Sansom, A., 2004. Diffuse pollution: an introduction to the problems and solutions. IWA Publishing, London. ISBN:1-900222-53-1

Casal-Campos, A., Jefferies, C., Perales-Momparler, S., 2012. Selecting SUDS in the Valencian Region of Spain. Water Pract. Technol. 7, 1, published online. http://dx.doi.org/10.2166/wpt2012.001

Castro-Fresno, D., Andrés-Valeri, V.C., Sañudo-Fontaneda, L.A., Rodriguez-Hernandez, J., 2013. Sustainable Drainage Practices in Spain, Specially Focused on Pervious Pavements. Water, 5, 1, 67–93. http://dx.doi.org/10.3390/w5010067

Charlesworth, S.M., 2010. A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. Journal of Water and Climate Change, 1, 3, 165-180. http://dx.doi.org/10.2166/wcc.2010.035

Charlesworth, S.M., Perales-Momparler, S., Lashford, C., Warwick, F., 2013. The sustainable management of surface water at the building scale: preliminary results of case studies in the UK and Spain. J. Water Supply Res. T., 62, 8, 534-544. http://dx.doi.org/10.2166/aqua.2013.051

Chouli, E., Aftiasb, E., Deutscha, J.C., 2007. Applying storm water management in Greek cities: learning from the European experience. Desalination, 210, 61-68. http://dx.doi.org/10.1016/j.desal.2006.05.033

Cole, R.J., 2012a. Regenerative design and development: current theory and practice. Building Research & Information, 40, 1, 1-6. http://dx.doi.org/10.1080/09613218.2012.617516

Cole, R.J., 2012b. Transitioning from green to regenerative design, Building Research & Information, 40, 1, 39-53. http://dx.doi.org/10.1080/09613218.2011.610608

de Haan, F.J., Ferguson, B.C., Adamowicz, R.C., Johnsone, P., Brown, R.R., Wong, T.H.F., 2013. The needs of society: A new understanding of transitions, sustainability and liveability. Technol. Forecast. Soc. Change., 85, 121-132. http://dx.doi.org/10.1016/j.techfore.2013.09.005

de Haan, J.H., Rotmans, J., 2011. Patterns in transitions: Understanding complex chains of change. Technol. Forecast. Soc. Change., 78, 90-102. http://dx.doi.org/10.1016/j.techfore.2010.10.008

Díaz, M., Darnhofer, I., Darrot, C., Beuret, J.E., 2013. Green tides in Brittany: What can we learn about niche–regime interactions? Environ. Innovation Soc. Transitions, 8, 62-75. http://dx.doi.org/10.1016/j.eist.2013.04.002

du Plessis, C., 2012. Towards a regenerative paradigm for the built environment. Building Research & Information, 40, 1, 7-22. http://dx.doi.org/10.1080/09613218.2012.628548

Duffy, A. and Jefferies, C. 2011. Research Report: Developing a Framework to guide Urban Water Systems Transitions. SWITCH Deliverable D1.1.1. Last accessed on 13-May-2014 from http://www.switchurbanwater.eu/outputs/pdfs/W1-3_GEN_MAN_D1.3.3_SWITCH_Transition_Framework.pdf

Elzen, B., Geels, F.W., Leeuwis, C.S., Van Mierlo, B., 2011. Normative contestation in transitions 'in the making': animal welfare concerns and system innovation in pig husbandry (1970–2008). Research Policy, 40, 263-275. http://dx.doi.org/10.1016/j.respol.2010.09.018

Escuder-Bueno, I., Castillo-Rodríguez,J.T., Zechner, S., Jöbstl, C., Perales-Momparler, S., Petaccia, G., 2012. A quantitive flood risk analysis methodology for urban areas with integration of social research data. Nat. Hazards Earth Syst. Sci. 12, 2843-2863. http://dx.doi.org/10.5194/nhess-12-2843-2012

Escuder-Bueno, I., Andrés-Doménech, I., Morales-Torres, A., Perales-Momparler, S., 2013. Towards energy efficiency improvement in urban areas stormwater management: the E2STORMED project [in Spanish], in: Vallés-Morán, F.J., Andrés-Doménech, I., Escuder-Bueno, I., López-Jiménez, P.A., Marco S., J.B. (Eds), 2013, III Jornadas de Ingeniería del Agua. La protección contra los riesgos hídricos. Vol 2, pp. 51-58. ISBN:978-84-267-2071-9

European Commission, 2012. Guidelines on Best Practices to Limit, Mitigate or Compensate Soil Sealing. Commission Staff Working Document. SWD(2012) 101 final/2. Brussels. Last accessed 21-May-2014 from http://ec.europa.eu/environment/soil/pdf/guidelines/EN%20-%20Sealing%20Guidelines.pdf

Ferguson, B.C., Brown, R.R., Deletic, A., 2013a. Diagnosing transformative change in urban water systems: Theories and frameworks. Global Environmental Change 23, 264-280. http://dx.doi.org/10.1016/j.gloenvcha.2012.07.008

Ferguson, B.C., Frantzeskaki, N., Brown, R.R., 2013b. A strategic program for transitioning to a Water Sensitive City. Landsc. Urban Plan., 117, 32-45. http://dx.doi.org/10.1016/j.landurbplan.2013.04.016

Ferguson, B.C., Brown, R.R., de Haan, F.J., Deletic, A., 2014. Analysis of institutional work on innovation trajectories in water infrastructure systems of Melbourne, Australia. Environ. Innovation Soc. Transitions, In Press. http://dx.doi.org/10.1016/j.eist.2013.12.001

Frantzeskaki, N., Loorbach, D., Meadowcroft, J., 2012. Governing societal transitions to sustainability. International Journal of Sustainable Development, 15, 1/2, 19-36. http://dx.doi.org/10.1504/IJSD.2012.044032

Gasper, R., Blohm, A., Ruth, M., 2011. Social and economic impacts of climate change on the urban environment. Current Opinion in Environmental Sustainability, 3, 150-157. http://dx.doi.org/10.1016/j.cosust.2010.12.009

Geels, F.W., 2004. From sectorial systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. Research Policy, 33, 897-920. http://dx.doi.org/10.1016/j.respol.2004.01.015

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy, 36, 3, 399-417. http://dx.doi.org/10.1016/j.respol.2007.01.003

Geels, F.W., 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environ. Innovation Soc. Transitions, 1, 1, 24-40. http://dx.doi.org/10.1016/j.eist.2011.02.002

Grau E., A., 1995. Benaguasil during the ancient regime [In Valencian]. Ilmo. Ayuntamiento de Benaguasil, Valencia. ISBN:84-606-2634-2.

Hamel, P., Daly, E., Fletcher, D., 2013. Source-control stormwater management for mitigating the impacts of urbanisation on baseflow: A review. Journal of Hydrology, 485, 201-211. http://dx.doi.org/10.1016/j.jhydrol.2013.01.001

Hoxie, C., Berkebile, R., Todd, J.A., 2012. Stimulating regenerative development through community dialogue. Building Research & Information, 40, 1, 65-80. http://dx.doi.org/10.1080/09613218.2011.628546

Jefferies C., Duffy A.M., 2011. The SWITCH Transition Manual. ISBN 978-1-899796-23-6. Last accessed 13-May-2014 from http://www.switchurbanwater.eu/outputs/pdfs/W1-3_GEN_MAN_D1.3.4_SWITCH_Transition_Manual.pdf

Jones, P.S., Davis, A.P., 2012. Spatial Accumulation and Strength of Affiliation of Heavy Metals in Bioretention Media. J. Environ. Eng., 139(4), 479–487. http://dx.doi.org/10.1061/(ASCE)EE.1943-7870.0000624

Loorbach, D.A., 2007. Transition Management: New mode of Governance for sustainable development. PhD, Erasmus University, Rotterdam. ISBN: 978-905727-057-4. Last accessed 13-May-2014 from http://repub.eur.nl/pub/10200

Loorbach, D., Rotmans, J., 2010. The practice of transition management: Examples and lessons from four distinct cases. Futures 42, 3, 237-246. http://dx.doi.org/10.1016/j.futures.2009.11.009

Lundy, L., Wade, R., 2011. Integrating sciences to sustain urban ecosystem services. Progress in Physical Geography, 35, 5, 653-669. . http://dx.doi.org/10.1177/0309133311422464

Mang, N.S., 2009. Toward a Regenerative Psychology of Urban Planning. Saybrook Graduate School and Research Center, ProQuest, UMI Dissertations Publishing, 3368975. Last accessed 21-May-2014 from http://gradworks.umi.com/33/68/3368975.html

Mang, P., Reed, B., 2012. Designing from place: a regenerative framework and methodology, Building Research & Information, 40, 1, 23-38. http://dx.doi.org/10.1080/09613218.2012.621341

Marsalek, J., Chocat, B., 2002. International Report: Stormwater management. Water Sci. Technol., 46, 6-7, 1-17.

McCormick, K., Anderberg, S., Coenen, L., Neij, L., 2013. Advancing sustainable urban transformation. J. Clean Prod., 50, 1-11. http://dx.doi.org/10.1016/j.jclepro.2013.01.003

Millán R., P., Nácher-Rodríguez, B., Hernández C., C., M. Martín, Vallés M., F.J., Andrés-Doménech, I., Perales-Momparler, S., 2013. Comparative analysis of runoff from a permeable pavement and from a conventional road [In Spanish], in: Vallés-Morán, F.J., Andrés-Doménech, I., Escuder-Bueno, I., López-Jiménez, P.A., Marco S., J.B. (Eds), 2013, III Jornadas de Ingeniería del Agua. La protección contra los riesgos hídricos. Vol 2, pp. 131-138. ISBN:978-84-267-2071-9

Næss, P., Vogel, N. 2012. Sustainable urban development and the multi-level transition perspective. Environ. Innovation Soc. Transitions, 4, 36-50. http://dx.doi.org/10.1016/j.eist.2012.07.001

Nevens, F., Frantzeskaki, N., Gorissen, L., Loorbach, D., 2013. Urban Transition Labs: co-creating transformative action for sustainable cities, J. Clean Prod., 50, 111-122. http://dx.doi.org/10.1016/j.jclepro.2012.12.001.

Nicolau B., J., 1990. Pages of Benaguasil history [in Valencian]. Ajuntament de Benaguasil, Benaguasil. ISBN:84-505-9891-5.

Novotny, V., Ahern, J., Brown, P., 2010. Water centric sustainable communities: planning, retrofitting, and building the next urban environment. John Wiley & Sons, Inc. New Jersey. ISBN 978-0-470-47608-6

Pahl-Wostl, C., Tàbara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E., Ridder, D., Taillieu, T., 2008. The importance of social learning and culture for sustainable water management. Ecological Economics, 64, 3, 484-495. http://dx.doi.org/10.1016/j.ecolecon.2007.08.007

Pedersen-Zari, M., 2012. Ecosystem services analysis for the design of regenerative built environments. Building Research & Information, 40, 1, 54-64. http://dx.doi.org/10.1080/09613218.2011.628547

Perales, S., Andrés, I., 2008. Sustainable Urban Drainage Systems: An alternative for Stormwater Management [In Spanish]. Revista Técnica de Medio Ambiente C&M Publicaciones, Madrid, pp. 92–104. ISSN:1130-9881

Perales, S., Valls, G., Coombs, P., 2011. Pluvial flood hazard maps: tools and case studies [In Spanish], in: Escuder-Bueno, I., Matheu, E., ltarejos-García, L., Castillo-Rodríguez, J.T. (Eds), 2012, Risk Analysis, Dam Safety, Dam Security and Critical Infrastructure Management, Taylor & Francis Group, London, pp. 129-137. ISBN 978-0-415-62078-9.

Perales-Momparler, S., Valls-Benavides, G., 2013. Sustainable Drainage Systems (SuDS). Paisea nº 024: Espacios del Agua. Paisea revista s.l. ISSN 1887-2557

Perales-Momparler, S., Hernández-Crespo, C., Vallés-Morán, F., Martín, M., Andrés-Doménech, I., Andreu A., J., Jefferies, C., 2014. SuDS Efficiency during the Start-Up Period under Mediterranean Climatic Conditions. Clean-Soil Air Water 2014, 42 (2), 178–186. http://dx.doi.org/10.1002/clen.201300164

Perales-Momparler, S., Jefferies, C., Periguell-Ortega, E., Peris-García, P.P., Munoz-Bonet, J.L., 2013. Inner-city SUDS retrofitted sites to promote sustainable stormwater management in the Mediterranean region of Valencia: AQUAVAL (Life+ EU Programme). NOVATECH Conference, Lyon, France.

Plaut, J.M., Dunbar, B., Wackerman, A., 2012. Regenerative design: the LENSES Framework for buildings and communities, Building Research & Information, 40, 1, 95-111. http://dx.doi.org/10.1080/09613218.2012.619685

Potter, K., Ward, S., Shaw, D., Macdonald, N., White, I., Fischer, T., Butler, D., Kellagher, R., 2011. Engineers and planners: sustainable water management alliances. Engineering Sustainability, 164, ES4, 239-247. http://dx.doi.org/10.1680/ensu.2011.164.4.239

Progress Consulting S.r.l. and Living Prospects Ltd., 2011. The role of regional and local authorities in promoting a sustainable water policy. Final Survey Report. Doc cdr-180. European Union. Last accessed 13th-May-2014 from http://portal.cor.europa.eu/europe2020/news/Documents/Water/Water%20Survey%20Full%20Report%20Final.pdf

Quist, J., Thissen, W., Vergragt, P.J., 2011. The impact and spin-off of participatory backasting: From vision to niche. Technol. Forecast. Soc. Change, 78, 883-897. http://dx.doi.org/10.1016/j.techfore.2011.01.011

Rauch., W., Seggelke, K., Brown, R., Krebs, P., 2005. Integrated Approaches in Urban Storm Drainage: Where Do We Stand? Environmental Management, 35, 4, 396–409. http://dx.doi.org/10.1007/s00267-003-0114-2

Reed, B., 2007. Shifting from 'sustainability' to regeneration. Building Research & Information, 35, 6, 674-680. http://dx.doi.org/10.1080/09613210701475753

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., and Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manage., 90, 5, 1933-1949. http://dx.doi.org/10.1016/j.jenvman.2009.01.001

Resolution of 31st October 2013, of the Infrastructure, Territory and Environment Regional Ministry, submitting to public information the revision of the Territorial Action Plan on Flood Risk prevention for the Valencian Region [In Spanish]. Diario Oficial de la Comunidad Valenciana 2013, 7159, 34289-34290.

Rotmans, J., Kemp, R., van Asselt, M., 2001. More evolution than revolution: transition management in public policy. Foresight, 3, 1, 15-31. http://dx.doi.org/10.1108/14636680110803003

Royal Decree 1290/2012 of 7th September amending both the Royal Decree 849/1986 of 11 April, approving the Regulation of Public Water, and Royal Decree 509/1996 of 15 March, developing the Royal Decree Law 11/1995 of December 28, laying down rules for urban waste water treatment [in Spanish]. Boletín Oficial del Estado 2012, 227, 66167–66194.

Royal Decree 233/2013 of 5th April regulating the National Plan to encourage house renting, building refurbishment and urban regeneration and renovation, 2013-2016 [in Spanish]. Boletín Oficial del Estado 2013, 86, 26623–26684.

Sánchez-Rodríguez, R., 2009. Learning to adapt to climate change in urban areas. A review of recent contributions. Current Opinion in Environmental Sustainability, 1, 2, 201-206. http://dx.doi.org/10.1016/j.cosust.2009.10.005

Smith, A., 2007. Translating Sustainabilities between Green Niches and Socio-Technical Regimes. Technology Analysis & Strategic Management, 19, 4, 427-450. http://dx.doi.org/10.1080/09537320701403334

Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Research Policy, 41, 6, 1025-1036. http://dx.doi.org/10.1016/j.respol.2011.12.012

Truffer, B., Störmer, E., Maurer, M., Ruef, A., 2010. Local strategic planning processes and sustainability transitions in infrastructure sectors. Environmental Policy and Governance, 20, 4, 258-269. http://dx.doi.org/10.1002/eet.550

Tukker, A., Butter, M., 2007. Governance of sustainable transitions: about the 4(0) ways to change the world. J. Clean Prod., 15, 1, 94-103. http://dx.doi.org/10.1016/j.jclepro.2005.08.016

United States Environmental Protection Agency (USEPA), 2008. Managing wet weather with Green Infrastructure. Green Streets. Low Impact Development Center, EPA, USA. Last accessed 21-May-2014 from http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_munichandbook_green_streets.pdf

van der Brugge, R., Rotmans, J., 2007. Towards transition management of European water resources. Water Resour. Manag., 21, 1, 249-267. http://dx.doi.org/10.1007/s11269-006-9052-0

van der Steen, P., Howe, C., 2009. Managing water in the city of the future; strategic planning and science. Rev. Environ. Sci. Biotechnol., 8, 115–120. http://dx.doi.org/10.1007/s11157-009-9154-2

van Herk, S., Zevenbergen, C., Ashley, R., Rijke, J., 2011. Learning and Action Alliances for the integration of flood risk management into urban planning: a new framework from empirical evidence from The Netherlands. Environmental Science & Policy, 14, 5, 543-554. http://dx.doi.org/10.1016/j.envsci.2011.04.006

Willems, P., Olsson, J., Arnbjerg-Nielsen, K., Beecham, S., Pathirana, A., Bülow G., I., Madsen, H., Nguyen, V.T.V., 2012. Impacts of Climate Change on Rainfall Extremes and Urban Drainage Systems. IWA Publishing. ISBN: 9781780401256

Wong, T.H.F., Brown, R.R., 2009. The water sensitive city: principles for practice. Water science and technology, 60, 3, 673-682. http://dx.doi.org/10.2166/wst.2009.436

Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray R.; Shaffer, P., 2007. The SUDS Manual. CIRIA C697. London. ISBN:978-0-86017-697-8

Woolthuis, R., Hooimeijer, F., Bossink, B., Mulder, G., Brouwer, J., 2013. Institutional entrepreneurship in sustainable urban development: Dutch successes as inspiration for transformation. J. Clean Prod., 50, 91-100. http://dx.doi.org/10.1016/j.jclepro.2012.11.0

ANNEX 2: SuDS Efficiency during the Start-Up Period under Mediterranean Climatic Conditions.

Abstract

This paper presents the performance of a number of sustainable drainage systems (SuDS) in the city of Xàtiva in the Valencia Region of Spain relatively soon after their construction. The systems studied comprise two roadside swales, one detention basin receiving runoff from one of the swales and one green roof to a school. The SuDS were installed under an EU LIFE+ project intended to demonstrate their practicability, application, and behaviour under Mediterranean rainfall conditions. Most of the systems installed were in new developments but the green roof was retrofitted to a school within Xàtiva which is a dense urban area. Full flow monitoring was undertaken and spot samples were taken to give a preliminary assessment of water quality performance. The early results presented in the paper demonstrate the effectiveness of the systems under typical Mediterranean conditions which comprise intense rainfall from September to December and little or no precipitation at other times of the year. It is concluded that SuDS can be effectively introduced in the Mediterranean region of Spain.

Keywords

Green roofs; Sustainable drainage systems; Swales; Wash-off; Water quality.

Abbreviations

BOD_5, 5-day biological oxygen demand; **COD**, chemical oxygen demand; **DO**, dissolved oxygen; **HRT**, hydraulic retention time; **SuDS**, sustainable drainage systems; **TN**, total nitrogen; **TP**, total phosphorus; **TSS**, total suspended solids; **VSS**, volatile suspended solids.

1. Introduction

Sustainable drainage systems (SuDS) were introduced in Northern Europe and the United States to address deteriorating water qualities in lakes, rivers and groundwater caused principally by urban and related developments. Notable applications in the USA, where they are termed structural stormwater best management practices (BMPs), are to be found in Florida (lake and groundwater quality), Maryland (water quality in Chesapeake Bay) and Colorado (preservation of flows in small streams). In Germany many regions require SuDS on new developments and highways to protect groundwater quality, while in Sweden and Scotland, the driver for SuDS is the quality of rivers and lakes [1, 2].

A wide range of types of SuDS are available to the city and water planner. Some are easier to locate close to buildings and roads (Higher up the treatment train), others provide greater amounts of treatment and storage while others fit better into local landscapes, providing more habitat. The SuDS triangle (quantity/quality/amenity) is used to illustrate the balance that must be met [1].

It is not appropriate to provide an exhaustive list of SuDS in this paper, but source control systems include green roofs, soakaways, permeable paving systems and roadside swales; site controls include detention basins and infiltration systems, and regional controls comprise ponds and wetlands.

It is now realized that SuDS address several agendas in addition to that of receiving water quality. Increasing knowledge of climate change has sharpened concerns that rainfall may change both in terms of average rainfall, with effects on water resources, and rainfall intensities which may cause greater amounts of flooding. Since the philosophy of SuDS is to provide space for surplus water within the urban area, additional resilience to floods and droughts can thus be built automatically into SuDS. The storage gives a measure of protection against flooding through attenuation but it also can provide a source of water for re-use within the city. A further issue is the amount of energy used in the water and drainage sector, and by preventing rainwater from flowing into the drains, there will be less pumping and less treatment to provide water for irrigation and toilet flushing.

In a scientific and engineering sense, the performance of a SuDS component depends on a range of local conditions such as the construction of the component, soil types and rainfall regime and depends on the local climate. However, to operate in the long term, SuDS must be fully integrated into the city framework and local operational practices and the arrangements for SuDS in a very dense Spanish city will be very different from those in a city with less impermeable area and different operational practices.

Transposition of the EU Water Framework Directive [3] to the Spanish regulatory framework has introduced the principle of achieving a good ecological status to River Basin Management Plans highlighting a lack of regulation, amongst others, in relation to combined sewer overflows

(CSOs). A recent legislative instrument [4] establishes new procedures for obtaining or maintaining discharge permits for both stormwater and combined sewer systems. Even though best available (and affordable) practices and technical knowledge are specified, the legislation requires future technical rules to be developed. Nevertheless, article 259 of [4] indicates that new urban developments should incorporate measures to reduce runoff entering the drainage system. It would be desirable that the technical rules should also embody recent European Commission guidelines for water management which promote the use of SuDS [5].

This paper focuses on three types of SuDS: a green roof, two roadside swales, and an infiltration basin. By covering roof areas with soil and vegetation, green roofs can achieve numerous benefits. Stormwater runoff can be reduced and attenuated so that the urban water balance approaches a natural state [6]. Moreover, there are other collateral benefits including thermal improvements, indoor noise, air pollution reduction and social and amenity benefits. By using swales, the total runoff volume is reduced through infiltration and storage; peak flows are lowered also through infiltration and the flow is retarded by increased channel roughness [7]. The performance of detention basins is also improved when located on a soil where infiltration is possible.

Two matters are of specific interest in this work: (i) the adequacy of SuDS in the Mediterranean context, and (ii) their performance during the start-up period, i.e., during the months just after their construction. In contrast to Northern Europe, experience of SuDS in Mediterranean regions over the last decade is still poor [2, 8]. Recently, in Spain, real effort has been put in to develop expertise and guidelines [9 - 11] and some sites have already been implemented mainly in the northern coastal region [12] but also in Barcelona, Madrid, and the Valencia region [13]. The transition to this new approach to manage urban stormwater has been started in Spain but water planners and stakeholders are still reluctant to incorporate these solutions because their hydraulic and quality performances are still not well demonstrated locally, highlighting the need for experiments and monitoring under Mediterranean climatic conditions.

The influence of the start-up period on the hydraulic performance of green roofs is poorly addressed in the reviewed literature and this paper analyses the response of SuDS during their implementation period. However, since both the vegetation and the substrate undergo major changes with time, it can be expected that the age of the infrastructure will influence the runoff dynamics [6]. The same *a priori* conclusions must apply to swales and infiltration basins since the age of vegetation also influences the soil infiltration capacity.

In addition to their ability to retain water and the corresponding benefits to drainage management, green roofs have the ability to remove pollutants; however, the evidence for the effectiveness of pollutant removal is mixed [6]. The use of fertilizers, the composition of the soil, type of vegetation, pollutants, atmospheric pollution, among others, are all factors, some extremely site specific, that affect the quality of runoff from green roofs [14].

Sedimentation in grass swales is the principal treatment mechanism with filtration playing a minor but highly effective role [15] in reducing total suspended solids [16]. In this type of study, analysis of nutrients is also important due to the importance of nutrient control for many water bodies. Frequently, depending on the rainfall intensity, flooding from sewers occurs and significant nutrients loads are discharged into receiving water bodies. High variability in nutrient removal is observed in field studies for this type of SuDS [16].

It has also been shown that the pollutant mass washed off the surface of the contributing catchment during a storm event depends on the number of antecedent dry days [17] while others have found that the maximum rainfall intensity significantly affected pollutant concentrations [18]. Low correlation coefficients have been found between rainfall, rainfall intensity, temperature, and antecedent dry period with particulate pollutants, whereas the coefficient between rainfall duration and particulate pollutants was positive and relatively large [19].

During this start-up period, the vegetation is establishing and soils are still not well-compacted so the quality performance is not what is to be expected in the long term.

2. Materials and Methods

2.1. The AQUAVAL project

AQUAVAL ("The efficient management of rain water in urban environments") is a project funded by the EU LIFE+ Community Initiative whose main target is to find, implement and promote innovative solutions to decrease the impacts of developments on quantity and quality of urban runoff (e.g. flooding, CSOs, pollution, drought, etc.) within the Valencia Region of Spain. The project started on January 1, 2010, and is due to conclude by the end of September 2013. The project comprises the construction and monitoring of pilot SuDS as an important step towards the required change of paradigm. The scope of the project includes production of sustainable urban stormwater management plans and policies with the aim of making drainage infrastructure versatile and able to cope with the effects of climate change.

The municipality of Xàtiva is a municipal member of the AQUAVAL project in which the guiding principle is to ensure that rainwater management is included in water and land use planning, making the best use of landscape and morphology in order to integrate water infrastructure using SuDS, adding social and environmental values. Pilot SuDS locations in Xàtiva were chosen in places that have the ability to alleviate current problems of frequent flooding and CSO discharge, are typical of the Mediterranean region with its characteristic long hot droughts broken by high intensity storms, and is a dense and highly impermeable city with a combined sewer system.

2.2. Site descriptions

Xàtiva is located in the western Mediterranean on the Spanish coast. Its climate is Mediterranean, mild and semi-arid. The average temperature is around 16ºC, (10ºC in January and 27ºC in August) with extreme maxima which can reach 47 ºC in summer. The average annual rainfall is close to 690 mm, with very strong seasonality (Spanish Meteorological Agency, AEMET). Rain storms are usually concentrated in autumn, typically with very high peak intensities. This climate regime differs significantly from that of more northern and temperate climates where SuDS originated, justifying the value of properly monitored pilot projects.

Two of the new SuDS were in a new urban area to the north of Xàtiva and one was in the city centre. Site 1 (38º59'47.13''N 0º31'53.67''W) provides a 170 m^3 storage volume (Fig. 1). This volume manages runoff from 1900 m^2 of the adjacent road pavement and around 11 100 m^2 from the Sports City (a new sports complex). It comprises a 1.1 m wide (on average), 75 m long swale which is linked to an infiltration basin (50 m^2 base area), both retrofitted within the Sports City. Overflows occur to a nearby stormwater pipe.

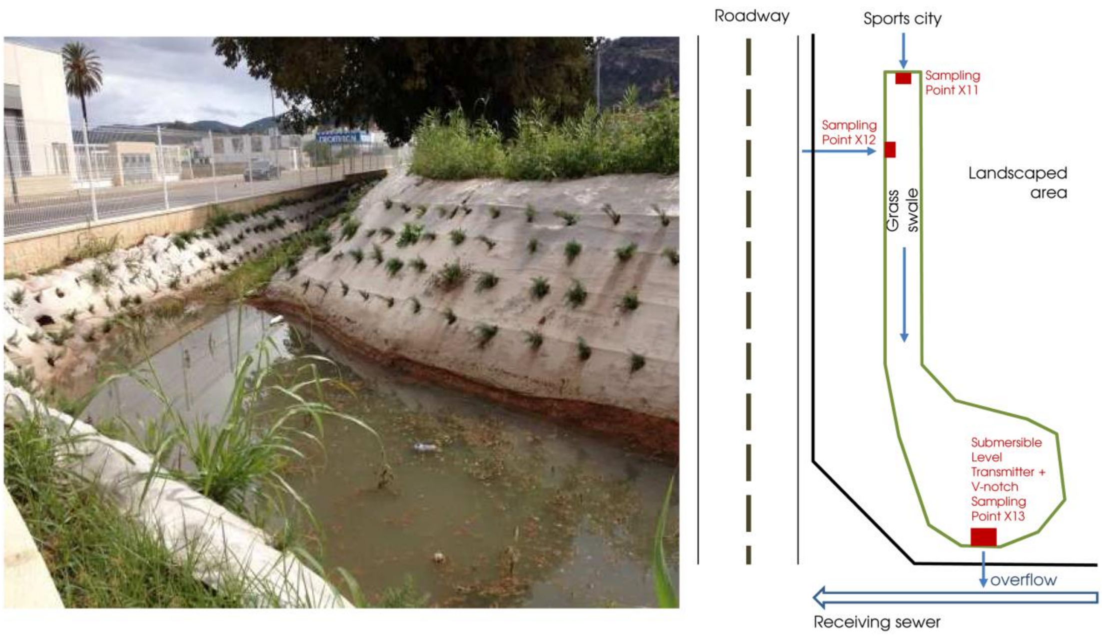


Figure 1. *Site 1. Infiltration basin. Photo (left) and monitoring points scheme (right).*

Site 2 (38º59'25.21''N 0º32'04.80''W) is located between a new urban development and a section of a ring road that had no drainage infrastructure and contributed to flooding of an industrial area downhill (Fig. 2). A 1.7 m wide swale has been constructed in the verge of the road, replacing the flat green area that was in the original plans. Four pedestrian crossings and 5 transverse structures act as barriers of low permeability to slow the flow. The swale is divided in two sections of 275 m and 95 m length respectively, and there are two emergency spillways to direct overflow to a stormwater pipe nearby. The monitoring focused on the longest section with a total catchment area of 7000 m^2 (both public and private road pavement) and a storage volume of 218 m^3.

Figure 2. *Site 2. Roadside swale. Photo (left) and monitoring points scheme (right).*

The Gonzalbes Vera Public School, located in the heart of the city of Xàtiva (38º59'26.80''N 0º31'04.31''W), was chosen as site 3 (Fig. 3). 475 m^2 of the roof has been retrofitted with a green roof and the playground has been re-paved with porous concrete. The substrate of the vegetated roof has a density of 1060 kg m^{-3} and is rich is organic matter (29%), total nitrogen (0.27%) and phosphorus (0.57% as P_2O_5). The depth of substrate is 10 cm and it is planted with a variety of *Sedum*. Monitoring activities reported here comprised water quantity and quality measurements from a section of the new green roof (218 m^2) as well as runoff from the remainder of the conventional roof which was untouched (107 m^2).

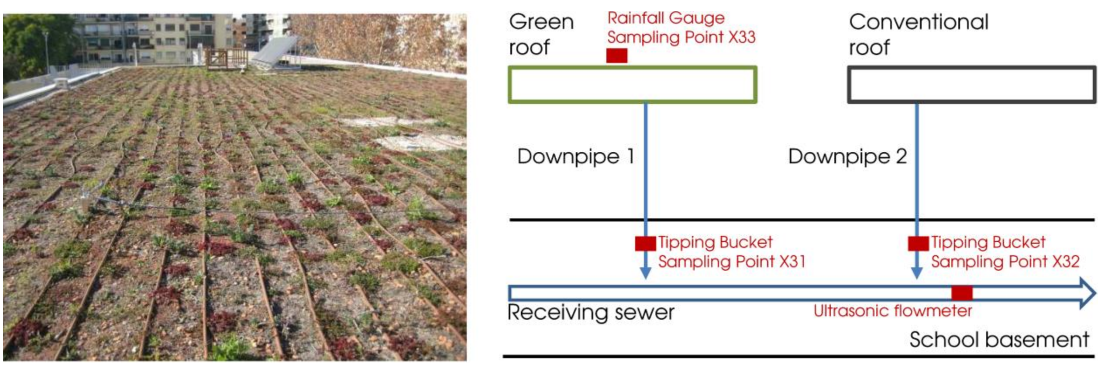


Figure 3. *Site 3. Green roof. Photo (left) and monitoring points scheme (right).*

The three SuDS systems were commissioned in August 2012, and the monitoring equipment was installed the following month.

2.3. Monitoring of quantity and quality variables

From a quantitative point of view, the main hydraulic variable of interest is the rate of overflow spills from each of the SuDS into the receiving sewer. This flow was measured with different equipment, depending on the type of SuDS and on the installation characteristics. Discharges from the infiltration basin and from the roadside swale were measured with V-notch weirs (90º), the hydraulic head over the vertex being recorded by mean of a level probe. Sewer flows were measured with ultrasonic flow meters that record both depth and flow velocity in the sewer. Finally, the flow rate through the downpipes of the green roof was monitored with tipping bucket flow gauges. In this case, every time the bucket tips, an electrical pulse is recorded. All this equipment was calibrated in the laboratory, especially the tipping buckets to know accurately the volume of water causing each tip. Finally, data loggers recorded the outputs from the level sensors, ultrasonic flow meters and tipping buckets.

Level probes at 1 and 2 were Mercoid SBLT2-5-40-ETFE submersible level transmitters with a measuring range up to 3.5 m (±9 mm). Each transmitter was connected to a Lufft OPUS 20 LF8120.30 datalogger with external sensors (temperature, humidity and analog input 4/20 mA). Bühler Montec Xytec7050 free surface ultrasonic flow monitors devices with data loggers were also located at 1 and 2.

A digital output signal is activated if the monitored variable exceeds a defined threshold. When this occurs the device sends an alert SMS to selected cellular phones. A minimum number of tips for the tipping bucket in the conventional roof downpipe was defined as the threshold so that the related rainfall depth produced runoff in the system. Water quality samples were generated by the trigger and had to be collected. Finally, hourly rainfall data in Xàtiva was collected by the Spanish Meteorological Agency (AEMET). Table 1 summarises the equipment installed and the monitoring periods. Quantity sampling points are indicated in Figs. 1 - 3.

A total of nine water sampling points were used (Figs. 1 - 3). There were three sampling points at sites 1 and 2 corresponding to the two inputs and the output from the swales to the sewer system. For site 1 (Fig. 1) they were from the Sports City (point 11) and the adjacent roadway (point 12). For the North Ring Road (Fig. 2) the inflows were from the residential area (point 21) and the adjacent North Ring Road itself (point 22). In both systems, the water was collected using 2 L plastic bottles with one bottle per sampling point per event. The bottles were filled at the beginning of each rain event. Accordingly, the water quality corresponded to the first wash off. The output bottles (points 13 and 23) were filled only if there were discharges and, consequently, the water quality was the result of all the processes (sedimentation of total suspended solids, sorption, biodegradation, volatilization) that occurred inside the swales during the event, whose performance depends on hydraulic retention time (HRT) and other environmental factors. However, when HRT is low, the output is mainly related to the input pollutograph as there is no time for treatment other than sedimentation.

Zone	1	2		3		
Devices	Double V Notch weir + level sensor	V Notch weir + level sensor	Ultrasonic flow meter	Tipping bucket	Tipping bucket	Ultrasonic flow meter
Monitored variable	Level over the weir	Level over the weir	Level + flow velocity	Tipping pulses	Tipping pulses	Level + flow velocity
Output results	Flow discharge from the infiltration basin	Flow discharge from the roadside swale	Sewer flow	Flow discharge from the existing roof	Flow discharge from the green roof	Sewer flow
Monitoring starting date	27/09/2012	19/09/2012	19/09/2012	18/10/2012	18/10/2012	18/10/2012

Table 1. *Monitoring of quantity variables.*

Samples from both parts of the school roof, vegetated (point 31) and conventional (point 32), were collected in four bottles linked to the tipping buckets (two bottles per tipping bucket). The boxes where the buckets were placed were designed to allow the bottles to be filled consecutively at the start of the rain event and thus, there were a total of four samples per event. Finally, one bottle was located on the roof to collect rain water and atmospheric deposition (point 33).

Event	Start date / time	End date / time	Previous dry inter-event time (days)	Event duration (h)	Event rainfall depth (mm)	Water Quality Monitoring		
1	27/09/2012 12:00	30/09/2012 12:00	28.50	72	92.0	1	2	
2	12/10/2012 17:00	13/10/2012 00:00	12.75	7	35.4	1	2	3
3	19/10/2012 21:00	21/10/2012 12:00	6.87	39	23.8	1	2	3
4	25/10/2012 05:00	25/10/2012 19:00	3.71	14	5.4			
5	30/10/2012 13:00	31/10/2012 06:00	4.75	17	5.4			
6	09/11/2012 06:00	15/11/2012 17:00	9.00	155	199.6	1	2	3
7	17/11/2012 21:00	19/11/2012 03:00	2.17	30	8.0			
8	26/11/2012 20:00	27/11/2012 16:00	7.71	20	9.4			
9	25/12/2012 23:00	26/12/2012 06:00	28.29	7	4.6	1	2	

Table 2. *Key features for rainfall recorded events.*

Water samples were analysed for organic matter, nutrients and solids. Chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) were analysed using a Spectroquant® Analysis System by Merck. Five day biological oxygen demand (BOD_5) was measured using OxiTop®. Total suspended solids (TSS) and volatile suspended solids (VSS) were determined according to the Standard Method for Examination for Water and Wastewater [20]. Turbidity was measured with a turbidimeter TN100-Eutech Instruments. In addition, the following were measured in situ: water temperature, pH, conductivity and dissolved oxygen (DO) all with WTW® probes. The events monitored for water quality are indicated in Tab. 2.

3. Results and discussion

3.1. Rainfall pattern during the start-up period

Monitoring began at the end of September 2012 with the most torrential event recorded during the autumn of 2012 (event 1 in Tab. 2) and it was the first significant period of rainfall following the construction of the SuDS. This meant that the start-up period began with relatively extreme heavy rainfall conditions: 92 mm in 3 days; with approximately 50% of this amount falling between 12:00 and 14:00 on September 28. The previous dry period was close to one month so that pollutant accumulation on the contributing surfaces was likely to be significant. After this torrential event, 8 additional episodes were recorded during the following three months. Table 2 summarizes key features of each event recorded: starting and ending dates, previous dry inter-event time, duration, and rainfall depth.

3.2. Hydraulic performance

Several variables relating to the hydraulic performance of each SuDS have been deduced for each pilot. For sites 1 and 2, overflows from the basin to the receiving sewer were characterrized by the spill volume and peak flow. Hydrographs in the receiving sewer were monitored so that they could be compared with the swale overflows to assess differences between peak flows and their time of occurrence. Finally, runoff volumes and peak flows at site 3 were obtained for both the conventional roof and the green roof. The hydrograph of the receiving sewer to which both downpipes were connected was also monitored. A summary of all these results is shown in Tab. 3. Results for the green roof 3 were only obtained for event 8 and 9 as the reed switch of the tipping bucket was initially unreliable, although it was possible to collect water quality samples.

Runoff volumes entering the corresponding SuDS were calculated for each site and each event, runoff volumes being deduced from rainfall event depths, tributary areas and averaged runoff coefficients (Tab. 3). All flow during events 3, 4, 5, 7 and 8 was retained at sites 1 and 2 which both incorporate SuDS with both storage and infiltration capacity. It is concluded that runoff produced by rainfall events of depth up to 23.8 mm are completely retained at both locations. Event 2, with a rainfall depth of 35.4 mm produced overflow at both sites. Without the SuDS, the threshold before runoff occurred would be around 1-2 mm rainfall (corresponding to the paved areas close to 1 and 2).For the green roof, results shown in Tab. 3 highlight that the run-off threshold in this case is much lower (events 8 and 9 overflowed with 9.4 and 4.6 mm of rain-fall respectively), as the storage capacity of this site is very low.

Site Event	1 Spill volume (m^3)	1 Spill peak flow (l/s)	2 Spill volume (m^3)	2 Spill peak flow (l/s)	2 Sewer peak flow (l/s)	3 Conv. Roof peak flow (l/s)	3 Conv. Roof spill volume (m^3)	3 Green Roof peak flow (l/s)	3 Green Roof spill volume (m^3)	3 Sewer peak flow (l/s)
1	195.66	83.75	114.92	48.53	24.56	-	-	-	-	-
2	54.11	42.36	33.39	8.14	26.19	-	-	-	-	-
3	0	0	0	0	2.41	0.25	2.17	-	-	9.58
4	0	0	0	0	0.82	0.06	0.46	-	-	1.01
5	0	0	0	0	0	0.06	0.32	-	-	0.18
6	433.77	28.78	131.7	9.46	8.21	0.50	18.33	-	-	32.40
7	0	0	17.93	3.90	-	0.08	0.50	-	-	1.95
8	0	0	0	0	0.84	0.08	0.57	0.20	0.98	1.28
9	0	0	0	0	0	0.06	0.34	0.06	0.27	0.55

Table 3. *Hydraulic variables of each pilot performance for each recorded event.*

Hydrographs and water levels monitored at 1 and 2 show in detail the hydraulic performance of these SuDS. Figure 4 represents the hydraulic behavior of site 1 during event 2. This event was chosen among the huge amount of data collected and processed during the project, because it highlights properly the conclusions reached. Overflow occurs when the water level upstream exceeds the weir vertex level. Figure 5 shows results for the same event at the Ring Road site. Since the receiving sewer hydrograph was also monitored at this location, the results are more conclusive. It will be observed that each time the swale overflows (twice in event 2), the peak flow of the spill flow occurs later than the sewer peak flow. This highlights the attenuating ef-fect produced by the swale. Spill volumes during event 2 can also be calculated: 54.1 m^3 for 1 and 33.4 m^3 for 2. The spill volumes were compared with the infrastructure storage volumes (170 m^3 and 218 m^3 respectively). The result shows that spill volumes were smaller than those detained.

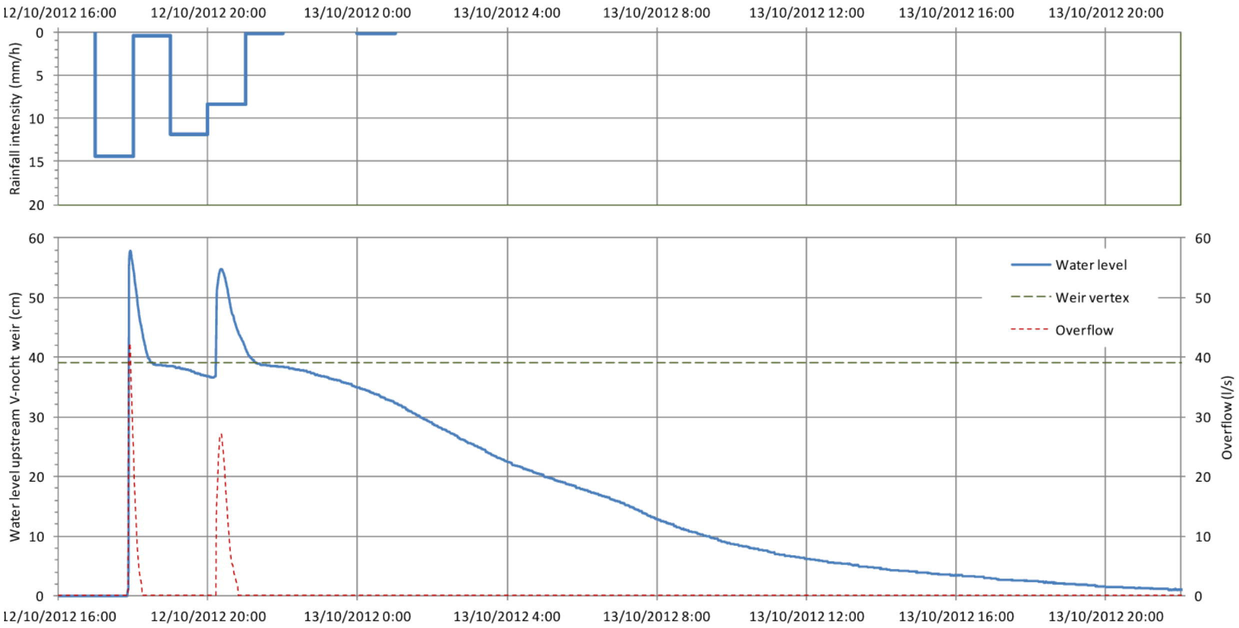


Figure 4. *Hydraulic performance for site 1 during event 2.*

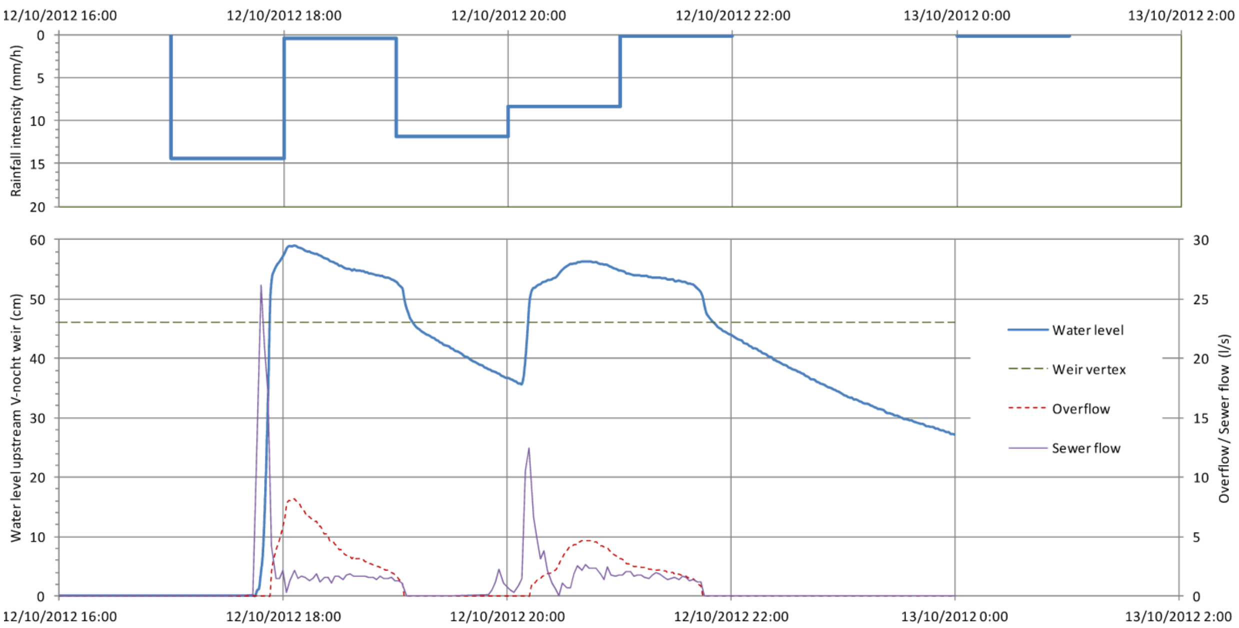


Figure 5. *Hydraulic performance for site 2 during event 2.*

The contributing area infiltration basin 1 (including the swale and the basin) is 13 000 m^2 and its averaged runoff coefficient (ratio between rainfall volume and runoff volume finally produced, related to soil type and land use) 0.76; the side roadway and the swale area that contribute to site 2 runoff is 7000 m^2 with an averaged runoff coefficient 0.93; the conventional roof is 107

m^2 while the green roof is 218 m^2. In both cases in site 3, the runoff coefficient must be set to 1 as the tributary area is exactly the same as the roof area.

The volumetric efficiency (VE) was calculated as:

VE = [1 – SV/RV] x 100

where SV is the spill volume and RV the runoff volume. VE shows the ratio between the runoff managed by the infrastructure (either detained or infiltrated or both) and the total runoff produced by the contributing area. Thus, a VE of 80% means that only 20% of the event runoff volume produced overflow. The results are summarized in Tab. 4 where the efficiencies obtained are always greater than 63% for sites 1 and 2. For events 3, 4, 5, 7, 8 and 9, the overall runoff was managed by the infrastructure giving efficiencies of 100%.

Event	Rainfall depth (mm)	1 Runoff volume (m^3)	1 Spill volume (m^3)	1 Volumetric efficiency	2 Runoff volume (m^3)	2 Spill volume (m^3)	2 Volumetric efficiency	3 Runoff volume (m^3)	3 Spill volume (m^3)	3 Volumetric efficiency
1	92.0	909.0	195.7	78%	598.9	114.9	81%	20.1	-	-
2	35.4	349.8	54.1	85%	230.5	33.4	86%	7.7	-	-
3	23.8	235.1	0.0	100%	154.9	0.0	100%	5.2	-	-
4	5.4	53.4	0.0	100%	35.2	0.0	100%	1.2	-	-
5	5.4	53.4	0.0	100%	35.2	0.0	100%	1.2	-	-
6	119.6	1181.6	433.8	63%	778.6	131.7	83%	26.1	-	-
7	8.0	79.0	0.0	100%	52.1	17.9	66%	1.7	-	-
8	9.4	92.9	0.0	100%	61.2	0.0	100%	2.0	1.0	52%
9	4.6	45.4	0.0	100%	29.9	0.0	100%	1.0	0.3	73%

Table 4. *Volumetric efficiencies of each pilot SuDS.*

The efficiency for the first result for the green roof (event 8) was poor (52%). This result is directly related to the start-up conditions with vegetation still not well developed, causing the retention capacity of the green roof not to be fully available. Moreover, the substrate was saturated as there had been two events following the long event of mid-November (event 6). The volumetric efficiency for the green roof increased to 73% for the last recorded episode (event 9). The main reason for this significant increase may be the preceding dry period of one month which was conducive to vegetation grow and soil drying. The performance of the green and conventional roofs was only measurable for events 8 and 9 due to the unreliability of some of the equipment. For event 8, the overflow volume for the conventional roof was 5.33 mm while for the green roof only 4.50 mm overflowed (16% less). For event 9, the figures were 3.18 mm and 1.24 respectively (61% less). These results show that the hydraulic performance of a green roof can increase significantly with a longer inter-event time.

3.3. Runoff water quality and SuDS response

There were two different inputs to the grass swale-infiltration basin system at the Sports City (site 1): one from the Sports City itself (point 11) and the other from the adjacent roadway (point 12) resulting in different rates and qualities of runoff (Fig. 6). In most cases observed to date, point 12 is the more contaminated of the two runoff inlets, as explained below.

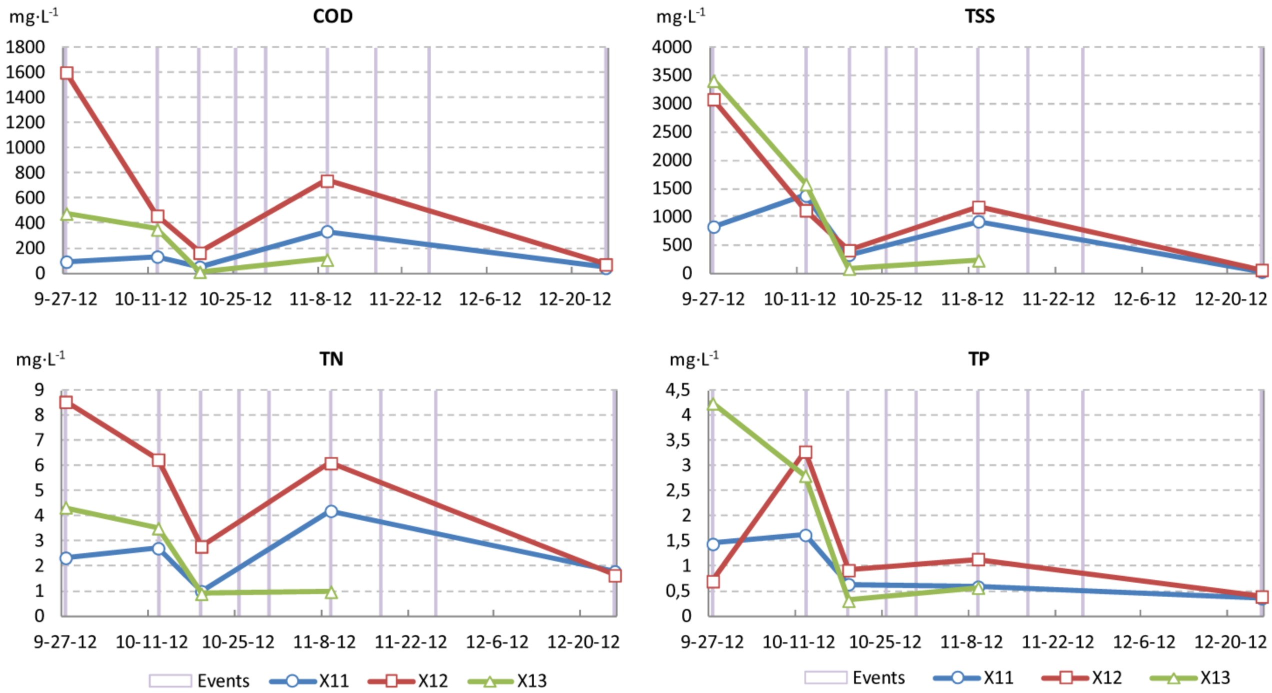


Figure 6. *Results of quality variables for monitored rainfall events in Sports City green swale (11: Sports City runoff, 12: roadway runoff, 13: green swale output). Columns indicate all rainfall events. The X-axis is time scaled.*

Water quality samples from a total of five storm events were analysed (Tab. 2). Three events stand out as being very intense (events 1, 2, and 6), the most intense being the first, giving rise to extreme concentrations of TSS (3083 mg·L^{-1}) and COD (1600 mg·L^{-1}) in the wash off of the adjacent roadway (12). These concentrations were very high compared with typical wastewater and are related to the storm intensity and the long antecedent dry period. In this regard, Sansalone et al. [21] showed that annual loads of TSS and COD transported in stormwater run-off from interstate and arterial roadways were approximately equivalent to that from untreated domestic wastewater generated by the population in the same urban area. Sansalone and Chad [22] measured high concentrations of suspended solids in runoff from small impervious watersheds, even higher than that measured here. In the subsequent events, input concentrations were noticeably lower, indicating that sediment on the roadway had already been washed off. The values monitored for the later events are compared with values reported for highways runoff by other authors [17]. Relationships BOD_5/COD were relatively low for every sampling point with mean values of 0.15, 0.09 and 0.16 for points 11, 12 and 13 respectively, indicating the low biodegradability of organic matter present in the runoff. In site 1, the average proportion of VSS to TSS was about 15% showing that the major fraction of solids was inorganic.

In the two first storm events, the grass swale in site 1 had a small treatment effect, the output sample producing higher TSS concentration than the inputs. This finding can be explained by the extreme intensity of these events which produced soil erosion in the areas surrounding the grass swale and the limited establishment of the vegetation at start-up. In the subsequent events, which were less intense, the output concentrations were lower than inputs. In the last, much smaller, event 9, the swale retained the overall pollution load because the spill volume was zero (Tab. 3).

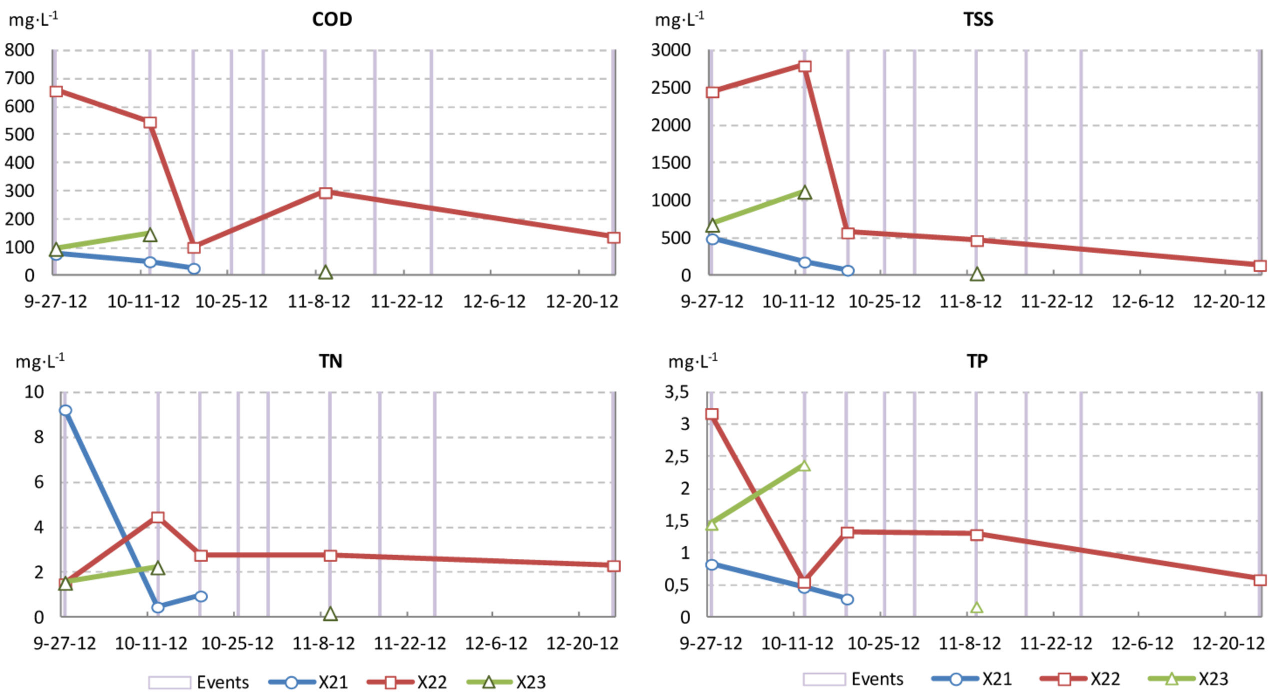


Figure 7. *Results of quality variables for monitored rainfall events in the North Ring Road grass swale (21: residential area runoff, 22: roadway runoff, 23: grass swale output). Columns indicate all rainfall events. The X-axis is time scaled.*

At the North Ring Road swale (site 2) the runoff from sampling point 2 produced generally higher concentrations of pollutants than the second inlet (point 21) (Fig. 7). A similar result was also obtained in pilot zone 1 (Sports City).

As in zone 1, COD and TSS concentrations measured in the roadway inlet (point 22) in events 1 and 2 were very high. The explanation for these results is again related to the intensity of the storm events and the long antecedent dry period for event 1. The influence of these factors has been observed by other authors [17, 18]. In addition, these high loads are also influenced by residues from the construction processes around, recently ended. In the subsequent events, the concentrations of COD and TSS in runoff were much lower.

Data from sampling points 21 and 23 (Fig. 7) were scarcer than from sampling point 22 principally because the bottles were not filled. This was due to the lower runoff rate to point 21 from the residential area. BOD_5 analyses for site 2 produced similar results to site 1 with relatively low BOD_5/COD ratios giving mean values of 0.15, 0.08 and 0.17 for points 21, 22 and 23 respectively.

The relationship between turbidity and TSS was similar in both zones 1 and 2, giving a good linear correlation ($r^2 > 0.9$) and similar turbidity/TSS relationships: around 0.6 for inlet points and 0.9 for the output samples. The study of these types of relationship is useful when considering whether turbidity probes might be installed as complementary devices to monitor pollutographs with fewer samples. The correlations obtained to date are promising in this sense. In zone 2, the proportion of VSS to TSS was around 13% showing that the major solids fraction is inorganic.

Events, 2, 3 and 6 (Tab. 2) were monitored for water quality at the school roof (site 3). Only 3 events were monitored as stated in the planning of the water quality campaign for this period. Runoff quality from both conventional and green roofs was poorer than the rain water (Tab. 5). The water from the vegetated roof was highly brown in colour but clear (turbidity <20 NTU). All the measured concentrations were higher, and specially COD much higher, than those for the conventional roof. The organic fraction was very high but was not easily biodegradable: the relationship between BOD_5 and COD, a good estimator of biodegradation, was only 0.05. The presence of organic matter is related to the substrate characteristics. Nutrient concentrations also increased by a factor of 9 for total nitrogen and 15 for total phosphorus after passing through the vegetated layer. However, in the case of total nitrogen, the increase cannot be assigned exclusively to the soil because the concentration of TN also increased by 4 from the conventional roof. Dry deposition of atmospheric nitrogen due to the proximity to a park with a very high birdlife is likely to be responsible for a significant load of TN. These results are similar to those obtained in other studies [23, 24], where increases of TP concentration were as high as observed here, whereas nitrogen concentrations decreased or, sometimes, increased slightly. The concentrations of suspended solids were also higher than for the rain water.

Quality variable	31			32			33		
COD (mg·L^{-1})	292	±	54	35	±	12	11	±	5
BOD (mg·L^{-1})	16	±	3	10	±	2	5	±	2
TN (mg·L^{-1})	7.74	±	1.41	3.08	±	1.26	0.86	±	0.53
TP (mg·L^{-1})	1.84	±	0.61	0.10	±	0.03	0.12	±	0.12
TSS (mg·L^{-1})	26	±	24	9	±	4	6	±	7
VSS (mg·L^{-1})	17	±	22	3	±	3	3	±	3
Turbidity (NTU)	18.3	±	10.5	12.1	±	4.4	3.8	±	3.5
Conductivity (µS·cm^{-1})	696	±	131	218	±	19	17	±	5
Temperature (ºC)	21.9	±	2.5	22.1	±	2.3	8.6	±	8.4
pH	7.92	±	0.27	7.57	±	0.45	7.01	±	0.79
DO (mg·L^{-1})	5.72	±	1.26	8.29	±	0.49	9.81	±	1.56
% Sat DO	66%	±	16%	95%	±	9%	99%	±	2%

Table 5. *Mean and standard deviation of quality variables at (31: green roof, 32: conventional roof, 33: rainfall).*

To date, there have been no significant differences between events because the start-up phase is still ongoing. Additionally, a slow change of concentration over time was observed for event 6: after 100 h from the first sample, the COD, TN, and conductivity halved but TP increased by 70%. Consequently, during the start-up phase, the vegetated roof increased pollutant concentrations, but when vegetation is well established, they should decrease over time as some references suggest [14].

4. Concluding remarks

Three SuDS sites have been constructed and monitored for the first time in the Mediterranean part of Spain. Two of the sites are new build swales and an infiltration basin and one is a retrofit green roof on an existing school. The hydrological and water quality results for swales and the basin clearly show significant attenuation of flows, volumes and concentrations. Outflow from the swales only occurred during three out of the nine events monitored and the spill events included an event with a maximum rainfall intensity of 45 mm in a 2 h period. Extremely high pollutant concentrations (and by inference, loads) were observed during the first rain event after commissioning. The high loads were believed to be due to a combination of residues from the construction process and from the very long antecedent dry period before the first event observed. Moreover, high rain intensities made this situation even worse because of a more powerful wash-off, although these data are believed to be typical of the Mediterranean climate. To date, water quality from the green roof has been worse than from the conventional roof owing to the high organic matter and nutrients in the substrate. However, when the vegetation matures, these results are expected to be better. Finally, the AQUAVAL project is also producing social benefits since local authorities are confident of their results and they are even considering retrofitting more SuDS infrastructure.

Acknowledgements

The research described in this paper has been carried out under the Life+ programme research project "AQUAVAL Sustainable Urban Water Management Plans, promoting SUDS and considering climate change, in the province of Valencia" (Life08ENV/E/000099), supported by ERDF funding of the European Union.

References

[1] B. Woods-Ballard, R. Kellagher, P. Martin, C. Jefferies, R. Bray and P. Shaffer. The SUDS Manual. CIRIA C697, London. 2007.

[2] J. C. Deutsch, M. Revitt, B. Ellis and L. Scholes. Review of the Use of Stormwater BMPs in Europe. DAYWATER, Report 5.1. 2003.

[3] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, Official Journal (OJ L 327). 2000.

[4] Real Decreto 1290/2012, de 7 de septiembre, por el que se modifica el Reglamento del Dominio Público Hidráulico, aprobado por el Real Decreto 849/1986, de 11 de abril, y el Real Decreto 509/1996, de 15 de marzo, de desarrollo del Real Decreto-ley, de 28 de diciembre, por el que se establecen las normas aplicables al tratamiento de las aguas residuales urbanas. BOE nº 227. 2012.

[5] European Commission. Guidelines on best practices to limit, mitigate or compensate soil sealing, SWD(2012) 101 final. 2012.

[6] J. Czemiel Berndtsson. Green Roof Performance towards Management of Runoff Water Quantity and Quality: A Review. Ecol Eng. 2010, 36 (4), 351-360.

[7] A. P. Davis, J.H. Stagge, , E. Jamil, H. Kim, Hydraulic performance of grass swales for managing highway runoff, Wat. Res. 2012, 46, 6775-6786.

[8] S. Perales and I. Andrés-Doménech. Los sistemas urbanos de drenaje sostenible: una alternativa a la gestión del agua de lluvia, Revista Técnica de Medio Ambiente C&M Publicaciones. 2008, 124 (Enero – Febrero 2008), p. 92–104.

[9] A. Casal-Campos, C. Jefferies and S. Perales-Momparler. Selecting SUDS in the Valencian Region of Spain, Wat. Pract. & Tech. 2012, 7 (1). doi:10.2166/wpt.2012.001.

[10] J. Puertas Agudo, J. Suárez López, J. Anta Álvarez. Gestión de las aguas pluviales: implicaciones en el diseño de los sistemas de saneamiento y drenaje urbano, Ministerio de Fomento, CEDEX, Centro de Estudios Hidrográficos, Monografías; M-98. 2008, ISBN 978-84-7790-475-5.

[11] J. J. Rodríguez Sánchez, A. Díaz Martínez. Guía técnica de diseño y gestión de balsas y otros dispositivos de retención de contaminantes en carreteras, Centro de Publicaciones, Ministerio de Fomento, CEDEX, Centro de Estudios de Técnicas Aplicadas. Manuales y recomendaciones; R-18. 2009, ISBN 978-84-7790-486-1.

[12] E. Gomez-Ullate, E. Castillo-Lopez, D. Castro-Fresno and J.R. Bayon, Analysis and Contrast of Different Pervious Pavements for Management of Storm-Water in a Parking Area in Northern Spain, Water Resources Management. 2011 , 25 (6), 1525-1535.

[13] D. Castro-Fresno, V. C. Andrés-Valeri, L. A. Sañudo-Fontaneda, Rodriguez-Hernandez, J. Sustainable Drainage Practices in Spain, Specially Focused on Pervious Pavements. Water 5, 2013 (1), 67-93. http://www.mdpi.com/2073-4441/5/1/67.

[14] D. B. Rowe. Green roofs as a means of pollution abatement. Environ. Pollut. 2011, 159, 2100-2110.

[15] A. Deletic, Modelling of Water and Sediment Transport over Grassed Areas, J. Hydrol. 2001, 248, 168-182.

[16] J. H. Stagge, A. P. Davis, E. Jamil, H. Kim Performance of grass swales for improving water quality from highway runoff, Wat. Res. 2012, 46, 6731-6742

[17] L.H. Kim, K. D. Zoh, S. M. Jeong, M. Kayhanian, M. K. Stenstrom, Estimating Pollutant Mass Accumulation on Highways during Dry Periods, J. Environ. Eng. 2006, 132, 985-993.

[18] I. M. Broodie, P. K. Dunn, Commonality of Rainfall Variables Influencing Suspended Solids Concentrations in Storm Runoff from Three Different Urban Impervious Surfaces, J. Hydrol. 2010, 387, 202-211.

[19] X. J. Zuo, D. F. Fu, H. Li, R. P. Singh, Distribution Characteristics of Pollutants and Their Mutual Influence in Highway Runoff, Clean-Soil Air Water, 2011, 39 (10), 956-963.

[20] APHA, Standard methods for the examination of water and wastewater, 17th ed., American Publish Health Associaton. Washington, DC (USA). 1991.

[21] J. J. Sansalone, J. M. Koran, J.A. Smithson, S. G. Buchberger, Physical Characteristics of Urban Roadway Solids Transported during Rain Events, J. Environ. Eng. 1998, 125 (5), 427-440.

[22] J. J. Sansalone, M. C. Chad, Fisrt Flush Concepts for Suspended and Dissolved Solids in Small Impervious Watersheds, J. Environ. Eng. 2004, 130, 1301-1314.

[23] J. Czemiel Berndtsson, T. Emilsson, L. Bengtsson, The Influence of Extensive Vegetated Roofs on Runoff Water Quality. Sci. Tot. Environ. 2006, 355, 48-63

[24] K. Vijayaraghavan, U.M. Joshi, R. Balasubramanian, A field study to evaluate runoff quality from green roofs. Wat. Res. 2012, 46, 1337-1345.

ANNEX 3: The sustainable management of surface water at the building scale: preliminary results of case studies in the UK and Spain.

Abstract

This paper reviews the devices suitable for building scale application and then outlines 3 case studies, 2 from Coventry, UK and one from Valencia, Spain. The first assesses the potential to retrofit an extensive green roof to the Frederick Lanchester Library, Coventry University. Costings are given, the structural strength of the building is investigated and various benefits of its installation, including potential to sequester and store carbon, are assessed. The second reports part of the AQUAVAL Project, Spain, whereby an extensive green roof was retrofitted to half of a school roof and porous concrete retrofitted to a pavement. Preliminary monitoring results show expected benefits, including attenuation of the storm peak and increased time to peak. The third case study using WinDes® software compared a conventionally drained new-build housing estate with a Sustainable Drainage System train of porous paving, bioretention and swales. Stormwater volume was reduced by ~20% and peak flow by >250 L s^{-1}. Addition of extensive green roofs to all buildings increased these differences and delayed return to baseflow conditions reflecting water stored in the management train components.

Key words

attenuation of the storm peak, carbon sequestration and storage, green roof, management train, SUDS.

1. Introduction

1.1. Legislation in Spain, and England and Wales

Various European-wide Directives including the Water Framework Directive (EU Directive 2000/60/EC) have had wide-ranging impacts on water resource and flood management strategies which are beyond the remit of this paper (cf. Castro-Fresno et al., 2013). However, policies specific to Spain as well as England and Wales have recently influenced surface water management strategies in those countries, emphasising the need for a more sustainable approach. In England and Wales, schedule 3 of the Flood and Water Management Act (FWMA), 2010, (http://www.legislation.gov.uk/ukpga/2010/29/schedule/3) encourages the use of Sustainable Drainage Systems (SUDS) to manage surface water in new build and redevelopments. These drainage systems have to be approved against a set of National Standards by a SUDS Approving Body (SAB) before construction is allowed to begin. Connection to the foul sewer is unchanged, but the automatic right of connection to a storm sewer will cease. Through the SABs, Local Authorities will have the responsibility of adoption and maintenance (Defra, 2010). The recommended drainage hierarchy is as follows:

1. Excess water should be discharged into the ground.
2. Or it can be discharged to a surface water body.
3. If neither of 1 or 2 above are suitable, then SAB approval will have to be sought for discharge to a surface water sewer.
4. In the event that scenarios 1-3 are not possible, then discharge to a combined sewer will have to be considered (Defra, 2011).

In the case of Spain, due to a relative lack of specific legislation to control Combined Sewer Overflows and limit resultant contamination, the Spanish Royal Decree 1290/2012 (http://www.boe.es/diario_boe/txt.php?id=BOE-A-2012-11779) was enacted encouraging the use of best practices and highlighting the importance of identifying landuse and land surface type in managing river basins effectively (Castro Fresno et al., 2013). The Spanish Royal Decree 233/2013 (http://www.boe.es/diario_boe/txt.php?id=BOE-A-2013-3780) promotes reduction of drinking water use, the sustainable management of urban runoff and the use of green roofs. It does this by funding new build projects as well as urban regeneration and renewal; this Plan is valid for 4 years, followed by review of progress.

1.2. Sustainable Drainage in context

The SUDS approach encourages infiltration into the ground, storage of water and conveyance of stormwater through the catchment. The main function is to slow water down, thus attenuating the storm peak and reducing the incidences of flooding in areas prone to excess stormwater overflow (Charlesworth and Warwick, 2012). At the same time as water is slowed, it is treated such that water quality is improved by the settling or trapping of polluted particulates, biodegradation of hydrocarbons and the systemic uptake of soluble contaminants where vegetated devices are utilized (Charlesworth et al., 2003).

There are many studies of the reasons for flooding in urban areas (e.g. Charlesworth and Warwick, 2012) including sealing of urban surfaces, the Urban Heat Island Effect (UHIE) and the wider effects of global climate change, so these will not be discussed here. There are also reviews of SUDS devices, their flexibility and multiple benefits including positive impacts on perceptions of human health, reduction in energy use as well as mitigating and adapting to changes brought about by climate change (e.g. Charlesworth, 2010; Fresno et al., 2005).

Since 80% of the buildings required in England and Wales by 2040 are already in existence (Charlesworth and Warwick, 2012), the focus for flood resilience and mitigation needs to be on retrofitting these measures to buildings which are currently standing; however, retrofit is still perceived as being difficult and expensive. A UK Environment Agency (2007) report highlights Permeable Paving Systems (PPS) in particular as having both 'net financial benefits for property owners as well as overall net economic benefits', furthermore stating that PPS 'costs less on a lifecycle basis than traditional surfaces' and citing ease of replacing block pavers and monetary savings due to obviating the need to pay a Water Company to deal with surface water if it is disposed of onsite.

The following section reviews devices specifically suitable for utilisation at the building scale, considering the efficient use of surface water including secondary use and efficient surface water disposal, as well as their suitability for retrofit. Case studies are then given to address the following three aims:

1. To illustrate the efficacy of the SUDS approach at various scales, from a single building to a new housing estate.
2. To illustrate the various benefits of SUDS retrofit at the single building scale.
3. To show the utility of monitoring demonstration sites.

2. Sustainable drainage at the building scale

Charlesworth and Warwick (2012) proposed the 'Bull's Eye' approach to designing SUDS for cities in which the urban centre included patches of suitable devices such as PPS, green walls and roofs, rain gardens, rainwater harvesting, pocket parks, road traffic islands and grass verges, most of which would be suitable for retrofitting, or new build, at the individual building scale. It is possible to use larger devices such as ponds and wetlands further out from the centre in the suburbs and then to design management trains around the urban periphery, none of which are suitable in an area of dense construction such as a city centre.

At the single building scale, however, it would be expected that rainwater would be disposed of onsite and that therefore the majority of management would be focused on source control such as green roofs, porous paving, rain gardens and rainwater harvesting. In the event that surface water runoff was to occur, swales could be utilised for conveyance, if appropriate for the site.

3. Efficiency of SUDS devices at the small scale

SUDS is multiple benefit and flexible, its efficiency can therefore be measured using several indicator roles. The main three are encapsulated in the 'SUDS triangle': water quantity reduction, water quality improvements and the provision of amenity and biodiversity benefits. There has been much research undertaken on the first two of these, and the benefits are clear (e.g. Blanc et al., 2012), however, whilst some research has been carried out on increased biodiversity (e.g. Brenneisen, 2006) and also amenity provision (e.g. Apostolaki et al., 2006), difficulties quantifying the latter have led to this area being researched much less. Reflecting other areas in which SUDS provide benefits, the SUDS 'rocket' proposed by Charlesworth & Warwick (2012), includes human health benefits, energy use reductions, mitigation of the UHIE as well as Carbon Sequestration and Storage (CSS) capability. Table 1 shows the efficiency of a variety of SUDS devices which could be used at the small, individual building scale with respect to a variety of measures.

All three case studies make use of green roofs, which, in terms of rainwater quantity benefits, will both retain water and also evapotranspire it into the overlying atmosphere, attenuating the storm peak. The volume of water able to be stored is highly dependent on antecedent conditions, i.e. the amount of water already present which is itself dependent on the depth and type of growing medium, type of drainage layer, vegetation used and regional weather (Stovin et al., 2012). In fact, Stovin et al. (2012) state that 'inter-event processes are complex' although over 50% cumulative annual rainfall retention by an experimental green roof was achieved. In general, providing the rainfall event does not exceed 5 mm, green roofs can prevent runoff, and in summer, can potentially retain up to 80% of incident rainfall which falls to a maximum of 35% in winter due to lowered evapotranspiration activity of the plants in winter (see Stovin et al. (2007) and references therein). The following case studies begin with a theoretical consideration of the retrofit of a green roof to an existing building, sited on Coventry University campus, and its potential benefits taking account of both stormwater attenuation and CSS. The second case study illustrates the success of such a green roof retrofit as well as rainwater harvesting to a school in Spain, and the third case study models the storm attenuation benefits of a SUDS management train to a larger area of regeneration in Coventry.

SUDS		What	Why	Where	Flood Risk Management Benefits	Water quality management benefits	Amenity and biodiversity benefits	Climate Change Mitigation Benefits	Landtake	Capital Cost	Maintenance Cost
Green roofs		The partial or complete coverage of a roof with vegetation or another growing medium.	Controls runoff close to source, stores it and filters out pollutants. Can provide other benefits.	Private in curtilage (source control)	θ θ	θ θ	θ θ θ	θ θ θ	NONE	£ £ £	£ £
Water Butts		Small, off-line storage devices designed to capture and store runoff for use in garden or other domestic.	Reduces potable water use.	Private in curtilage (source control)	θ θ θ	θ θ	θ	θ	£	£	£
Rainwater Harvesting		Water collection system from impermeable surfaces for non-potable water use.	Reduces potable water use.	Private in curtilage (source control)	θ θ θ	θ θ	θ	θ	£	£ £ £	£ £
Permeable Pavements		Porous surfaces to replaces traditional hard (impermeable) that allow water to infiltrate.	Water is stored and released gradually during which water quality is also improved. Can be used in permeable and impermeable ground conditions by incorporating some form of outflow and overflow component.	Private in curtilage (source control), car parks and some roads.	θ θ θ	θ θ θ	θ	θ	£	£ £	£
Bioretention		Depressions backfilled with a mixture of sand/soil, planted with vegetation. Water enters through a vegetated surface, trickling via a filter layer to a perforated pipe at the base.	Stores water, releases it gradually. Some water quality improvement provided by the filter layer.	Private in curtilage SuDS (source control, open spaces, next to roads and car parking.	θ θ θ	θ θ θ	θ θ θ	θ θ θ	£ £ £	£	£ £
Rain Garden		Vegetated area into which runoff is drained, attenuated and/or stored. Water infiltrates and taken up by plants.	Stores runoff, filters out pollutants, recharge groundwater.	Next to roads, in residential developments and throughout urban areas.	θ θ θ	θ θ θ	θ θ θ	θ θ θ	£ £	£	£
Swales		Shallow vegetated ditches, swales can run parallel to hard surfaces, allowing runoff to trickle down the sides into the base. Water conveyed in a controlled manner to another SuDS device or to the receiving watercourse.	Treats and attenuates runoff. Can be used in permeable or impermeable ground conditions (the latter if underdrained).	Open space, next to roads and car parks.	θ θ θ	θ θ θ	θ θ θ	θ θ	£ £ £	£	£ £

Key:

θ	LOW CONTRIBUTION	£	LOW COST
θ θ	MEDIUM CONTRIBUTION	£ £	MEDIUM COST
θ θ θ	HIGH CONTRIBUTION	£ £ £	HIGH COST

Table 1. *Benefits of SUDS devices (from Dickie et al. (2010) and Woods-Ballard et al. (2007)).*

3.1. Case study 1: Coventry University Library

The Frederick Lanchester Library (for location see Figure 1), built in 2000, was designed for 1 200 students and staff and occupies approximately 10 000 m^2 (Noon, 2008). It makes maximum use of natural light as well as innovative lighting technology and along with natural ventilation, energy consumption is significantly reduced compared to traditional air conditioned buildings (see Figure 2(a)).

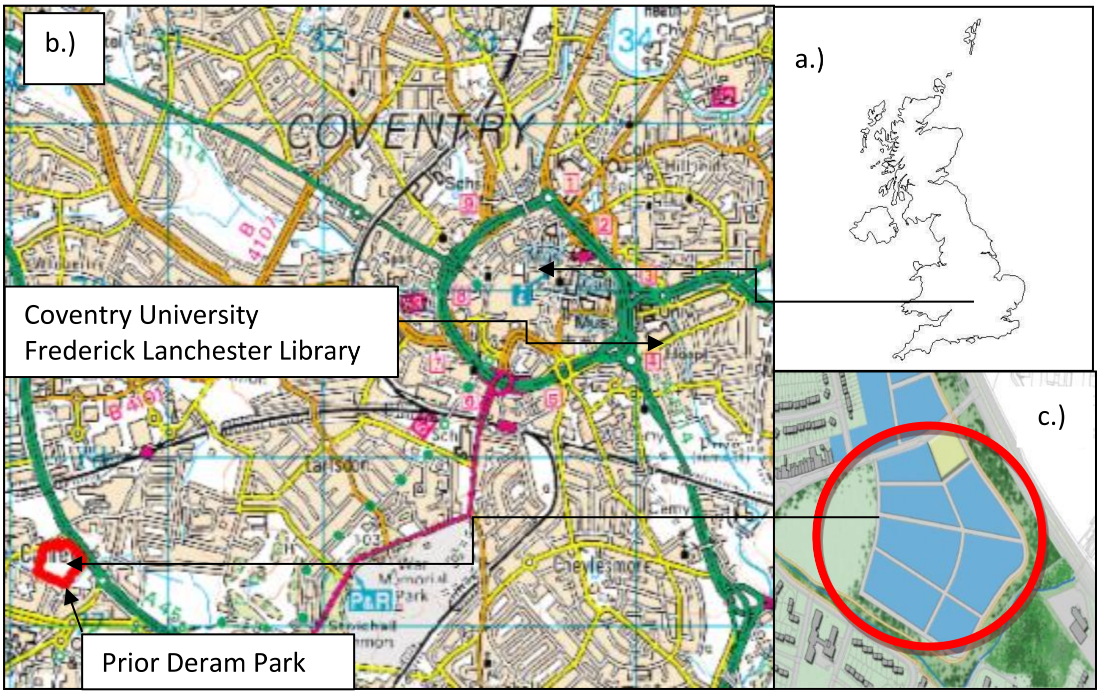


Figure 1. *The locations of: a.) Coventry; b.) Frederick Lanchester Library and Prior Deram Park; c.) a map of Prior Deram Park with the 250 house area highlighted.*

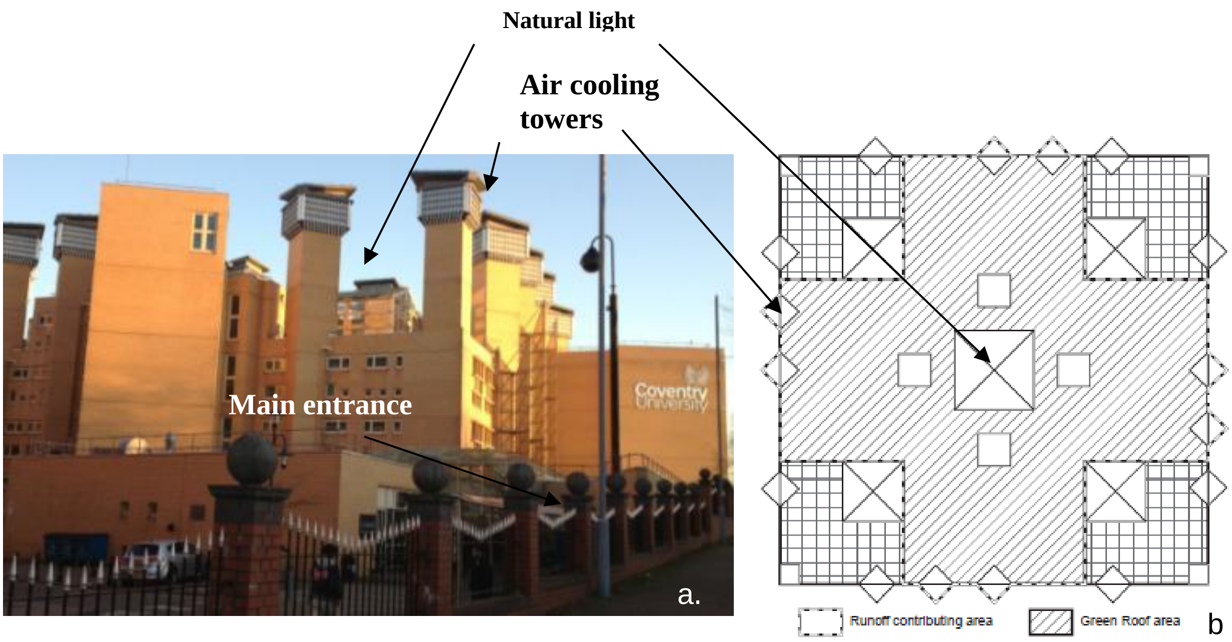


Figure 2. *a) The Frederick Lanchester Library, Coventry University, Coventry. b) Plan of the roof.*

However, it was planned, designed and built before the FWMA (2010) and thus does not include SUDS devices. The roof of the building offers opportunities to retrofit an extensive green roof. As

Figure 2b) shows, the roof is square in plan, 50 x 50 m, includes space for the light towers and has access pathways (not drawn for clarity) between which are stones to a depth of 7-8 cm (see Figure 3a) and 3b)). These stones are angular or rounded, and vary in weight from less than 7 g to over 130 g, an estimated load to the roof of around 123 kg m^{-2}.

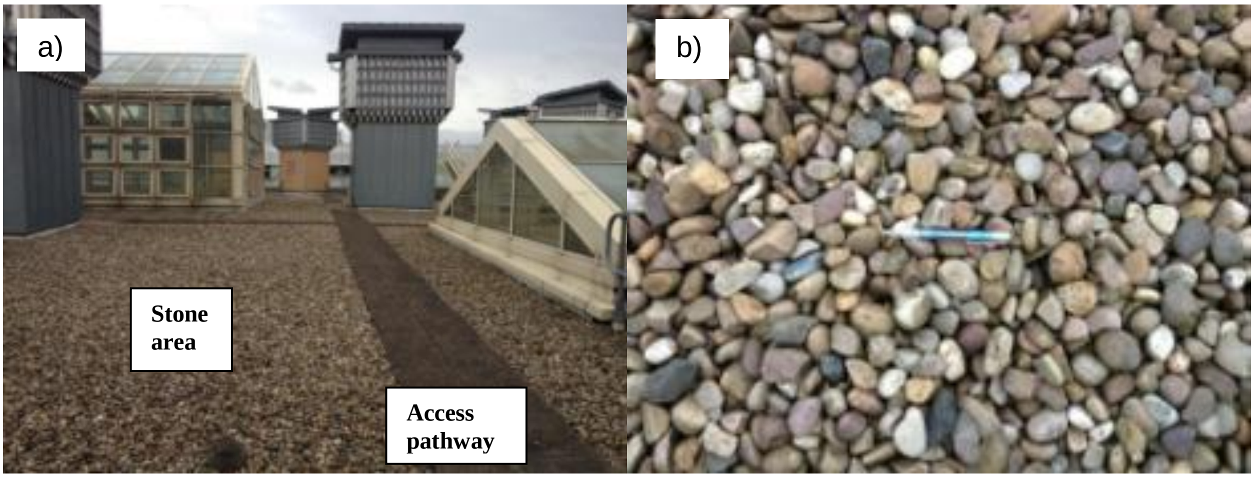


Figure 3. *a) View of the Frederick Lanchester Library roof; b) Close up of stones.*

The aim of this case study was to show the advantages of retrofitting an extensive sedum roof (with a pre-grown sedum blanket over an 8 cm thick layer of extensive soil substrate) onto the Frederick Lanchester Library, replacing the stones between the access pathways. Although further checks will have to be carried out at a later stage, it is envisaged that structural strength of the building is not a problem for the retrofitting, as the typical saturated weight of the proposed extensive substrate (96 kg m^{-2}) is lower than the one currently posed by the existing stone layer.

However, unless it can show advantages to the University, the cost would preclude its installation (estimations from the Bauder Group are of around £180 per m^2, i.e. £234 000 for the 1 300 m^2 proposed to be retrofitted). As set out above, energy usage for a building of its size is low, therefore the advantage of a green roof in reducing energy use is less relevant in this case. Since this is an extensive roof, there will not be access to it, therefore positive, direct human health impacts or amenity are, similarly, irrelevant. This therefore leaves the remaining two sides of the SUDS triangle: water quality and quantity and from the "rocket", CSS and mitigation of the UHIE. Of those four benefits, reduction of carbon is probably presently of most interest.

The University's 2011 Environmental Policy was to reduce carbon by 500 tonnes pa; it was awarded Silver in the EcoCampus Environment Management System during 2011. There are very few studies of green roofs estimating their CSS capabilities (Charlesworth, 2010); Getter et al. (2009) conducted a study of an extensive green roof (6 cm thick soil layer) in the USA, finding the whole roof (above-ground biomass, below-ground biomass and substrate) sequestered 375 gCm^{-2}

over a 2-year period. Using this figure, it is estimated that replacing 1 300 m^2 of the existing stone roof could sequester 487 kgC over a similar time frame to the Getter et al. (2009) study. Hence, greening the Library roof could go towards addressing some of the University's carbon reduction target.

Estimates by the manufacturer of the proposed green roof (Bauder pers. comm.) were that it could potentially store more than 25 L water m^{-2}. However, the attenuation benefits of the green roof took account of the data reviewed above, in which a rainfall event of up to 5 mm did not produce runoff. The calculations of storm peak attenuation were undertaken using WinDes®, a commercially available urban stormwater model (http://www.microdrainage.co.uk) that incorporates several SUDS devices at source, site and regional level. Results shown in Table 2 indicate peak flow reduction of between 78% and 98% of existing roof runoff could be expected, with time to peak delayed from 9 to 57 minutes.

Return Period (years)	**Stone roof**			**Green roof**		
	Critical Storm	**Max. runoff (l/s)**	**Time to peak (min)**	**Critical Storm**	**Max. runoff (l/s)**	**Time to peak (min)**
1	15 min Summer	23.9	9	15 min Summer	0.5	57
2	15 min Summer	30.8	9	15 min Summer	2.2	33
5	15 min Summer	39.8	9	15 min Summer	4.4	24
30	1 5min Summer	58.5	9	30 min Winter	13.0	22
100	15 min Summer	75.8	9	30 min Winter	17.1	21
100+20%CC	15 min Summer	91	9	30 min Summer	18.8	20

Table 2. *Expected peak flow reduction and delay benefits from retrofitting the green roof. Where "100+20%CC" = indicates taking Climate Change into account in calculations.*

3.2. Case study 2: Gozalbes Vera public school, Xàtiva (Valencia, Spain)

This case study is part of the AQUAVAL project (see www.aquavalproject.eu) and is based in Valencia, Spain, specifically the towns of Xàtiva and Benaguasil. The main aim of this part of the project is to show the value of SUDS demonstration sites, their design, construction and monitoring. These alternative solutions to traditional sewer systems are being monitored (for both water quality and quantity) for a year and it is expected that they will provide proof of concept in the field. Further details explaining site choice and community involvement can be found in Casals-Campos et al. (2012).

One of the demonstration sites is at Gozalbes Vera Public School, located in the centre of Xàtiva, (see Figure 4). This site was chosen for two main reasons: firstly, its ability to raise the awareness of SUDS to pupils from an early age and secondly, because the Xàtiva combined sewer system is overloaded and interventions such as SUDS have the potential to reduce peak flows, hence contributing to reducing the frequency of local flooding and also incidences associated with CSO overflows (Castro-Fresno et al., 2013).

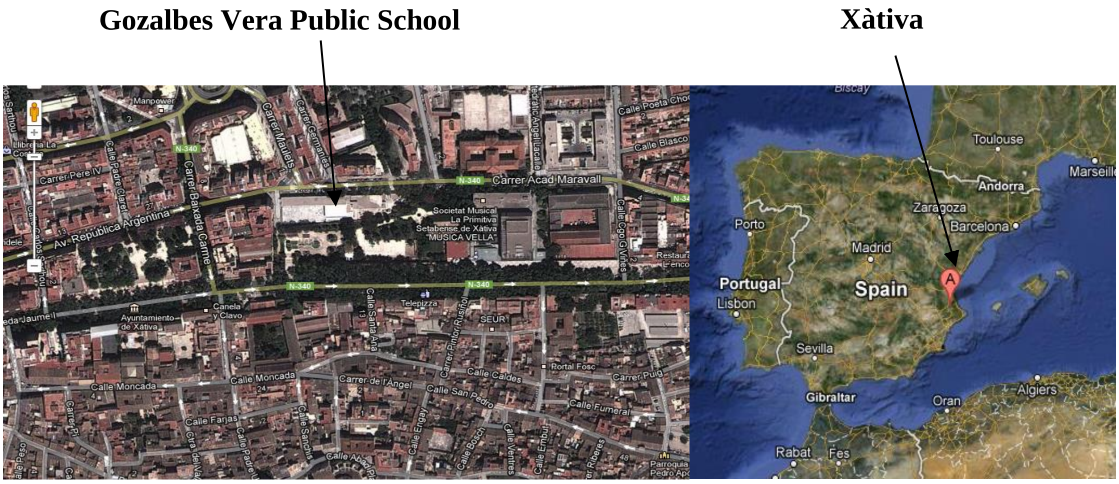


Figure 4. *Location of Gozalbes Vera Public School (from Google maps).*

% plants used	Sedum species
10	*Sedum album*
15	*Sedum acre*
20	*Sedum floriferum*
15	*Sedum spurium*
20	*Sedum reflexum*
10	*Sedum sediforme*
10	*Sedum sexangulare*

Table 3. *Sedum species and percentage used in the Xàtiva retrofitted green roof.*

This school has been retrofitted with three types of SUDS:

1. A 475 m^2 extensive green roof (Figure 5a)), with an enriched light soil layer, including fragments of brick to aid drainage, 10 cm thick (see Fig 5b) for detailed structure) and planted with 7 species of Sedum (see Table 3) which will retain the first 5 mm of rain (based on estimations in Stovin et al. (2012)).
2. A 3 000 litre rainwater tank (Figure 5c)) to collect water from a section of impermeable roof to use for watering plants on the patio and for cleaning tasks. This is being monitored for the amount of water subsequently used on these tasks.
3. Re-paving the sand playground (370 m^2) with 8 cm of porous concrete, covering a 25 cm clean gravel sub-base separated from the underlying soil by a porous geotextile layer. The

drainage capacity of the porous concrete was 200-400 L min^{-1} m^{-2} with a minimum cement content of 300 kg m^{-3} (Lafarge pers. Comm.).

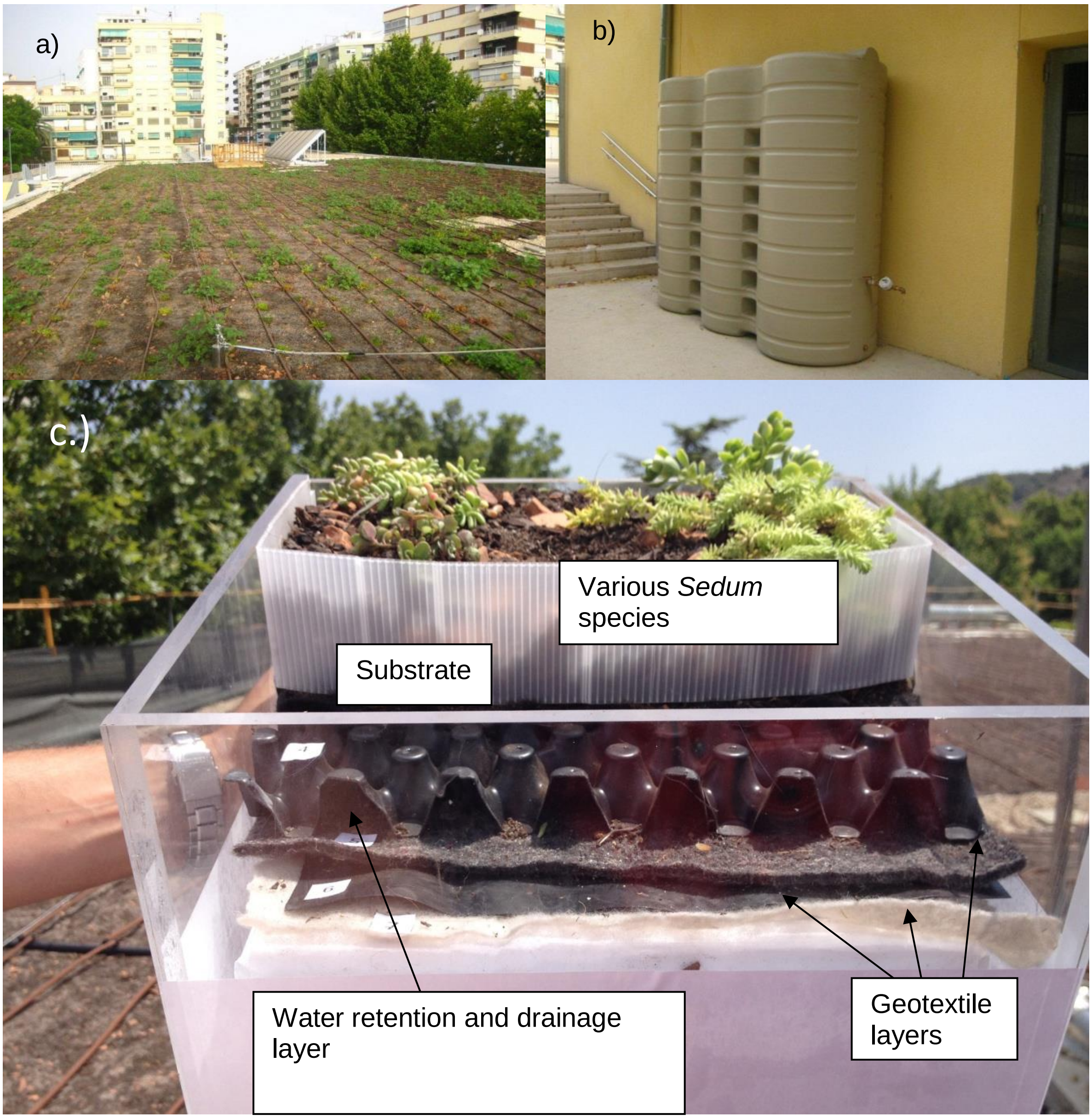


Figure 5. *Gozalbes Vera Public School SUDS retrofits. a) Extensive green roof; b) Rainwater tank c) Details of green roof structure.*

Due to budget restrictions, only part of the former cobbled roof was retrofitted, which allows comparison, at the same site, of the storm attenuation performance of both the green and cobbled areas. This is being undertaken using a tipping bucket fitted on two downpipes to measure runoff from the roofs; rainfall data was also collected at 10 min intervals by the Spanish Agency

AEMET, from the local Xàtiva Station. Data are retrieved on a monthly basis, any runoff from the green roof generates an SMS message for samples to be collected for water quality analysis. These real-life measurements can then be used to calibrate models of green roof efficiency in attenuating the storm peak which can then be used to assess larger scale green roof retrofit across the city. Water quality tests are being carried out on runoff from both locations, but monitoring, including that of rainfall amount, is ongoing and is not reported here.

In assessing storm peak attenuation by both retrofitted devices, a return period of 15 years was used in the design models since this is demanded under the Communidad Valenciana's PATRICOVA legislation (Olcina Cantos, 2010) for catchments >100 ha. Results indicated that the green roof delays runoff by about 30 min, with a 50% reduction both in peak flow and runoff total volume. Calculations using WinDes® (for details see case study 1) of the benefits of the porous concrete indicate that the reduction in peak flow would be around 70% for the rainfall design event. In terms of carbon sequestration, using assumptions from case study 1, the green roof could sequester about 180 kgC over a 2-year period (Getter et al., 2009).

3.3. Case study 3: Prior Deram Park, Canley, Coventry

The aim of the third case study was to increase the scale at which these approaches can be utilised, by modelling the impact of a SUDS management train on a 250-house new build estate. Prior Deram Park is part of the Canley Regeneration project and is located to the east of the site as shown in Figure 1. It is proposed that part of the site remains as open space, providing a children's play area, whilst 250 new houses at 50 houses ha^{-1} will be built on the rest (WSP Environmental Ltd & Coventry City Council, 2008). The access road layout has been designed and is shown on Figure 1c), but the layout for housing has yet to be decided. The housing styles will be mixed, with, for example, 116 three-storey terraced townhouses, 66 set out in two-storey terraces and the remaining 68 semi-detached, and will include private as well as social and affordable housing (Alliance Planning & Coventry City Council, 2008).

In order to assess the benefits of a SUDS management train to reduce surface water volume at Prior Deram Park, runoff was modelled from a conventional pipe-based drainage system and compared against a SUDS management train with and without green roofs using the modeling software WinDes® (see Case study 1 for more details) which has in-built SUDS devices and their performance criteria. Assumptions for climatic data were retrieved from the Flood Estimation Handbook (Institute of Hydrology, 1999). Following FWMA guidance (Defra, 2011), the pipe-based system should be designed to deal with a one in 30-year storm return period (standard-period average annual rainfall is 688mm) to prevent flooding on any part of the site. In the current simulation, both pipe-based and SUDS systems were designed with a one in 100-year 30 min winter storm return period and did not include the usual outflow control so that total outflow volumes could be compared.

The design of the SUDS management train was limited by the underlying clayey soil which restricted infiltration, and the fact that part of the site was previously used for landfill (WSP Environmental Ltd & Lockhart Garratt, 2008). Therefore, to reduce the possibility of groundwater pollution, infiltration SUDS devices such as PPS would need to be tanked and any runoff conveyed via pipes. Thus tank-based PPS as well as a single bioretention device were utilized for the driveways of each house for source control; swales were used for conveyance where possible and ponds for site control.

The results are shown in Figure 6, which illustrates the benefits of utilising a SUDS management train in comparison with pipe based conventional drainage whereby the peak flow is reduced by 252.7 L s^{-1}, and the time to peak extended by approximately 5 min. Response to rainfall is increased by about 8 min, and rainfall volume to outfall is reduced by approximately 20%. By adding green roofs to all houses to the SUDS train, the time to baseflow was increased by at least 15 min. This is likely to represent stormwater stored in the SUDS devices of the train and also in the green roofs (Berndtsson, 2010) which is subsequently released more slowly than the pipe-based system. As described above, the design flows are larger than that required by Defra (2011) and illustrate how the systems could cope with exceedance flows; the exercise shows the positive impacts of a SUDS management train on surface water management but in reality, flow can be further slowed using weirs and weir plates, or other flow constraining devices.

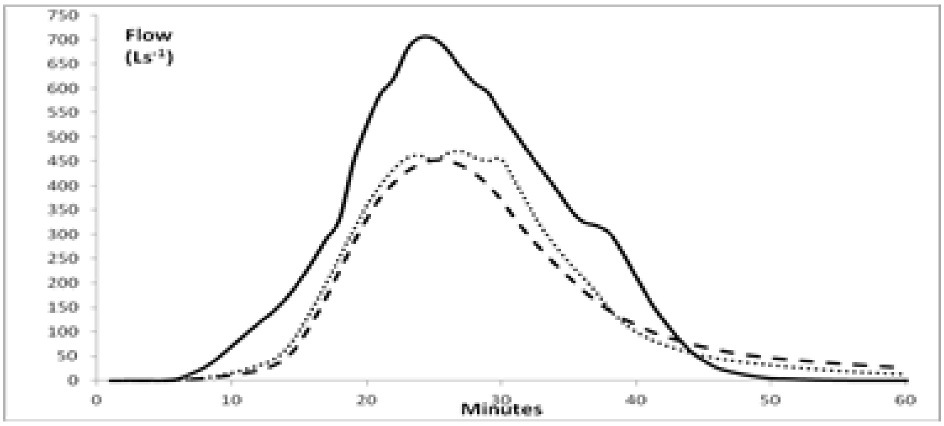


Figure 6. *Comparison of the impacts of conventional drainage (___), SUDS management train with (---) and without green roofs (...) on outflow at Prior Deram Park, Canley, Coventry.*

4. Conclusions

The three case studies detailed here show the benefits of retrofitting small scale SUDS devices to buildings mainly by attenuating the storm peak, but also other benefits in terms of carbon sequestration and storage. There is a singular lack of SUDS demonstration sites, and monitoring of those in the AQUAVAL project will generate data which will allow calibration of green roof efficiency models which can then be used at greater scales, for instance application of such retrofit approaches city-wide. The case studies also show that these benefits are possible at larger scales, by modeling the impacts on stormwater volume and peak flow by designing a SUDS management train and then adding green roofs. All three projects made use of green roofs as well as other devices, showing that they integrate well into a SUDS management train. In addition to addressing aspects of the SUDS triangle, particularly water quantity issues, green roofs can also mitigate impacts brought about by a changing climate, by absorbing and storing carbon already in the atmosphere, and calculations indicate the extent to which even a single roof can assist in this regard. The case studies presented here, both from Spain and the UK, demonstrate the potential for, and feasibility of, sustainable management of surface water at the building scale.

Acknowledgments

We are grateful to Bauder Ltd for information regarding green roof structure and costs and the following in relation to the Aquaval project: European Programme Life+, Diputación de Valencia, Ayuntamiento de Xàtiva, Ayuntamiento de Benaguasil, Fundación Comunidad Valenciana-Región Europea de la Generalitat Valenciana, PMEnginyeria, (Spain); University of Abertay-Dundee (Scotland).

References

Alliance Planning, Coventry City Council (2008) Affordable housing statement in support of planning application. Retrieved 25 February 2013, from http://planning.coventry.gov.uk/portal/servlets/AttachmentShowServlet?ImageName=791764

Apostolaki, S., Jefferies, C., & Wild, T. (2006) The social impact of stormwater management techniques. Water Practice & Technology 1 (1).

Berndtsson, C.J. (2010) Green roof performance towards management of runoff water quantity and quality: A review. Ecological Engineering, 36 (4) 351 - 360

Blanc J., Arthur, S. & Wright, G. (2012) Natural flood management (NFM) knowledge system: Part 1 - Sustainable urban drainage systems (SUDS) and flood management in urban areas. 32 pp. Retrieved 24 May 2013, from http://www.crew.ac.uk/sites/www.crew.ac.uk/files/publications/CREW_NFMProject_SUDS.pdf

Brenneisen, S. (2006) Space for Urban Wildlife: Designing Green Roofs as Habitats in Switzerland. Urban Habitats, 4, 1, 27-36.

Casal-Campos, A., Jefferies, C. & Perales-Momparler, S. (2012) Selecting SUDS in the Valencian Region of Spain. Wat. Pract. & Tech., 7, 1. doi:10.2166/wpt.2012.001

Castro-Fresno, D., Andrés-Valeri, V.C., Sañudo-Fontaneda, L.A. & Rodriguez-Hernandez, J. (2013) Sustainable Drainage Practices in Spain, Specially on Pervious Pavements". Water, 5, 67-93.

Charlesworth, S.M. & Warwick, F. (2012) Adapting and mitigating floods using Sustainable Drainage (SUDS). In: "Flood Hazards, Impacts and Responses for the Built Environment". Chapter 15, p 207- 234. J. Lamond, C. Booth, F. Hammond and D. Proverbs (eds), Taylor and Francis CRC press.

Charlesworth, S. (2010) A review of the adaptation and mitigation of Global Climate Change using Sustainable Drainage in cities. J. Water and Climate Change. 1, 3. 165-180.

Charlesworth S.M, E. Harker and S Rickard (2003) Sustainable Drainage Systems (SuDS): A soft option for hard drainage questions? Geography, 88(2) 99-107.

Defra (2010) What the Flood and Water Management Act means for property developers. Retrieved 24 May 2013, from http://archive.defra.gov.uk/environment/flooding/documents/policy/fwmb/fwma-developersfactsheet.pdf

Defra (2011) National Standards for sustainable drainage systems: Designing, constructing, operating and maintaining drainage for surface runoff. Retrieved 24 May 2013, from http://www.defra.gov.uk/consult/files/suds-consult-annexa-national-standards-111221.pdf

Dickie, S., McKay, G., Ions, L. & Shaffer, P. (2010) Planning for SuDs – making it happen. CIRIA C687. London.

EA (Environment Agency) (2007) Cost-benefit of SUDS retrofit in urban areas. Science Report – SC060024. 33pp.

Fresno, D.C., Bayón, J.R., Hernández, J.R. & Muñoz, F.B. (2005) Sustainable urban drainage systems (SUDS) [Sistemas urbanos de drenaje sostenible (SUDS)], Interciencia, 30, 5, 255-60 (in Spanish).

Getter, K. L., Rowe, D. B., Cregg, B. M & Andresen, J. A. (2009) Carbon Sequestration Potential of Extensive Green Roofs. Environ. Sci. Technol. 43, 7564-7570.

Institute of Hydrology. (1999) Flood Estimation Handbook. Wallingford, UK: Institute of Hydrology

Noon, P. (2008) The Lanchester Library — Building a Sustainable Library. Liber Quarterly 18 (2), 129-136.

Olcina Cantos J. (2010) Spatial planning processes, territorial planning law and flood risk in the region of Valencia (Spain). In: S. Menoni (ed) Risks Challenging Publics, Scientists and Governments. 191 -204. CRC Press.

Stovin V., Vesuviano, G. & Kasmin, H. (2012) The hydrological performance of a green roof test bed under UK climatic conditions. J. Hydrology, 414-415, 148-161.

Stovin V., Dunnett, N. & Hallam, A. (2007) Green roofs – getting Sustainable Drainage off the ground. NOVATECH 2007. Retrieved 24 May 2013, from, *http://www.greenroofresearch.co.uk/hydro/Stovin%20et%20al_2007_Green%20roofs_getting%20sustainable%20drainage%20off%20the%20ground(Novatech%20Green%20Roofs).pdf*

WSP Environmental Ltd, Lockhart Garratt (2008) Landfill statement. Retrieved 24 May 2013, from http://planning.coventry.gov.uk/portal/servlets/AttachmentShowServlet?ImageName=791759

WSP Environmental Ltd & Coventry City Council. (2008) Canley Regeneration Project - Outline Planning Application Environment Statement: Non-Technical Summary. Retrieved 24 May 2013, from http://planning.coventry.gov.uk/portal/servlets/AttachmentShowServlet?ImageName=791587.

Woods Ballard B., Kellagher R., Martin P., Jefferies C., Bray R. & Shaffer P. (2007) The SUDS Manual. CIRIA C697. London.

ANNEX 4: The role of monitoring sustainable drainage systems for catalyzing transition towards regenerative urban built environments: a case study in the Valencian region, Spain.

Abstract

Sustainable Drainage Systems (SuDS) are an alternative and holistic approach to conventional urban stormwater management that use and enhance natural processes to mimic pre-development hydrology, adding a number of well-recognized, although not so often quantified benefits.

However, transitions towards regenerative urban built environments that widely incorporate SuDS are “per se” innovative journeys that encounter barriers which include the limited evidence on the performance of these systems which, in many countries, are still unknown to professionals and decision makers. A further important barrier is the frequently poor interaction among stakeholders; key items such as SuDS provide collective benefits which also demand collective efforts.

With the aim of overcoming such innovation-driven barriers, six showcase projects (including rain gardens acting as infiltration basins, swales and a green roof) to demonstrate the feasibility and suitability of SuDS were developed and/or retrofitted in two cities of the Valencian region of Spain as a part of an EU project, and their performance was monitored for a year. The data acquired, after being fully analyzed and presented to a group of key regional stakeholders, is proving to be a valuable catalyst of the desired transition (for instance in influencing the support to SuDS in recent regional legislation).

This paper presents detailed data on how these urban ecological drainage infrastructure elements reduce runoff (peak flows and volumes) and improve its quality, contributing to the goal of healthier and livable cities. Furthermore, it shows how engagement can contribute to smarter governance in the sense of smoothing the difficulties faced by innovation when being presented, understood, and endorsed by professionals and decision-makers in the field of storm water management.

Keywords

Built environment; Mediterranean climate; Monitoring; Sustainable drainage systems; Transitions.

Abbreviations

BOD5, Five day biological oxygen demand; CFU, Colony-Forming Unit; COD, Chemical oxygen demand; DO, Dissolved oxygen; SuDS, Sustainable Drainage Systems; TN, Total Nitrogen; TP, Total Phosphorus; TSS, Total Suspended Solids; VSS, Volatile Suspended Solids; WWTP, Waste water treatment plant.

1. Introduction

Cities around the world face multiple challenges including expansion of paved areas, loss of vegetation cover and the effects of climate change. Conventional drainage systems are particularly impacted since normally their initial design was based on rapidly conveying stormwater runoff to receiving waters. All too often their capacity is now compromised by the increase of impermeable areas that produce larger amounts of runoff which is expected to increase further in many parts of the world due to climate change causing environmental damage not only because of changes to the flow regime but also to the increased loads of pollutants (Arnbjerg-Nielsen et al., 2013; Barbosa et al., 2012; Brown et al., 2009; Burns et al., 2012).

Sustainable Drainage Systems (SuDS) are an alternative and holistic approach to conventional stormwater management that use and enhance natural processes to mimic predevelopment hydrology. SuDS contribute to the mitigation of urban flooding and water pollution (Burns et al., 2012; Novotny et al., 2010) while saving energy in the urban water cycle and providing a non-conventional water resource, amenity, wildlife, carbon sequestration and storage, urban cooling, human-health and well-being (Charlesworth, 2010; Norton et al.; 2015). Hence, SuDS are part of the urban ecological infrastructure (Xu, 2012) that can be considered in broader greener plans (Li, 2005) as part of the transition towards regenerative urban built environments (du Plessis, 2012), a need highlighted by EU Ministers responsible for Urban Development (European Commission, 2010). However, such a journey encounters barriers including insufficient demonstration projects and a lack of interaction between stakeholders (Winz, 2014).

The complexity of such a transition process requires transition management (Jefferies and Duffy, 2011; van der Brugge and Rotmans, 2007), a governance approach that has the potential to overcome the inherent tension between the open-ended and uncertain process of sustainability transitions and the ambition for governing such a process through selective participatory activities of envisioning, negotiating, learning and experimenting (Frantzeskaki et al., 2012).

Sustainable transitions can be led by government (Loorbach and Rotmans, 2010), business (Loorbach et al., 2010), science, or civil society (Radywyl and Biggs, 2013; Woolthuis et al., 2013). In all cases it is crucial that, in order to enhance the quality of environmental decisions, stakeholder participation should emphasize empowerment, equity, trust and learning (Pahl-Wostl et al., 2008; Reed 2008; Smith and Raven, 2012). This requires the involvement of governmental and non-governmental multidisciplinary professionals (Jim, 2004; Potter et al., 2011), ever more important in a changing climate where the design and optimization of urban drainage infrastructure needs to be co-optimized with other objectives to keep cities habitable into the future (Arnbjerg-Nielsen et al., 2013).

The lack of available demonstration projects with appropriate monitoring is an important barrier (Brown and Farrely, 2009; Hunt and Rogers, 2005) that challenges the implementation of novel systems. Indeed, both government and industry require clear evidence about their benefits and costs, customized for the region of study, to be willing to invest. Furthermore, there is evidence that demonstration sites have facilitated the development of mature understanding of innovative approaches such as integrated urban water management (Mitchell, 2006). Demo sites help in the identification of opportunities and substantial cost savings for local communities that are not apparent when separate strategies are developed for each service (Anderson and Iyaduri, 2003).

Although SuDS have been implemented in many parts of the globe (Novotny et al., 2010), experience is limited in the Mediterranean region (Castro-Fresno et al., 2013; Charlesworth et al., 2013; Chouli et al., 2007) in particular characterizing the response of SuDS in the region, with its long dry periods and torrential rain (Millán et al., 2013; Perales-Momparler et al., 2014; Terzakis et al., 2008). Hence, there is a need for 'learning by doing' experiments which can demonstrate the effectiveness of this new approach (Barbosa et al., 2012; Binney et al., 2010; Casal-Campos et al., 2012; Lamera et al., 2014; Tukker and Butter, 2007) since, according to Nevens et al. (2013), experiments can be major triggers for the take-off and acceleration of transitions (Van der Brugge and Romans, 2007).

As Willke (2007) affirms, the creation of new knowledge becomes paramount for smart forms of governance. However, new knowledge has to fight for acceptance against conservatism and a host of difficulties, because knowledge is part of, and embedded in, social relationships. More specifically, new knowledge in civil engineering does not move easily into practice when professionals do not have codes, guidelines and/or evidence of proper performance that they can reference to justify due diligence in design and construction.

This paper aims to enhance smart governance in this context by providing information about the successful implementation and monitoring of SuDS showcase sites in Mediterranean Spain. These showcase sites are catalysts in the transition towards regenerative urban built environments in the region in the context of enhanced and intelligent governance (Halpin and Escuder, 2015; Perales-Momparler et al., 2015). In addition, this article expands the current list of references for improved urban ecological infrastructure, particularly scarce in the Mediterranean area and certainly improvable in terms of quantification of the benefits of SuDS, by demonstrating what success can look like (Binney et al., 2010).

2. Description of Showcase Sites

With the aim of overcoming barriers to innovation, six showcase sites (Fig. 1) demonstrating the feasibility and suitability of SuDS were developed in two cities of the Valencian region in Spain within the framework of the AQUAVAL EU project (Life08ENV/E/000099, www.aquavalproject.eu). The sewer system (mainly combined) in both urban areas suffered from lack of capacity during intense, frequent rainfall events causing pluvial flooding and the discharge of combined sewage into the receiving water courses.

Table 1 presents a summary of the roadside swales, detention-infiltration basin and green roof built in Xàtiva (29 400 inhabitants) and the several detention-infiltration basins and harvesting tank retrofitted in Benaguasil (11 300 inhabitants). All six sites are easily accessible for viewing by the public and include notice boards for information and educational purposes enhancing their value as showcase sites. More detailed descriptions and explanations can be found in Perales-Momparler et al. (2013 and 2014), and Casal-Campos et al. (2012) which also describes the decision-support process used for sites and SuDS options selection.

Fig. 1. *Showcase sites after SuDS development/retrofitting in Xàtiva (upper row) and Benaguasil (lower row).*

Site **Code: location**	**Type of SuDS**	**Main function**	**Criteria for site selection**	**Area of works / Drained area**	**Construction cost***
X1: Xàtiva Sports City	Infiltration basin	Runoff reduction	Drainage required and public space available	415 m^2 / 17 350 m^2 (Works include a 75 m long, 1.1 wide base swale, linked to 50 m^2 basin)	565 €/m^3 retention volume
X2: Xàtiva North Ring Road	Roadside swale functioning as a longitudinal infiltration basin	Runoff reduction and quality improvement	Drainage required and public space available	3 700 m^2 / 12 560 m^2 (1.7 m wide base)	175 €/m
X3:Gonzalbes Vera public school in Xàtiva	Green Roof	Runoff reduction and building insulation	Educational opportunity; comparison on runoff discharged from the green roof and from the conventional roof	475 m^2 / 475 m^2 (Monitored area: 218 m^2)	161 €/m^2
B1: Costa Ermita park in Benaguasil	Detention-infiltration basins	Sediments detention and runoff reduction	Public space available in an elevated town area	600 m^2 / 9 330 m^2	880 €/m^3 retention volume
B2: Benaguasil Youth Center	Underground-concrete rainwater harvesting tank	Rainwater harvesting	Educational opportunity and revival of a lost ancient practice	25 m^2 / 100 m^2	1 584 €/m^3 retention volume
B3: Les Eres industrial park in Benaguasil	Infiltration basin	Runoff reduction	Showcase for future expansion of industrial area and public space available	410 m^2 / 1 190 m^2	290 €/m^3 retention volume

* Final cost including works to redirect runoff, infrastructure required for monitoring tasks (monitoring equipment not included) and notice boards.

Table 1. *Summary description of showcase Sites.*

2.1. Monitoring of water quantity variables

Full rainfall and flow monitoring programmes were undertaken in each site to investigate their hydraulic response and performance (Perales-Momparler et al., 2014).

In Xàtiva, rainfall data was collected by the Spanish Meteorological Agency (AEMET). In Benaguasil, a Detectronic rainfall gauge (0.2 mm accuracy) with a Bühler Montec datalogger was installed.

The purpose of the monitoring was to quantify the rate and volume of overflow from each structure into the downstream system together with the volume of water detained or harvested. Different equipment was used depending on the SuDS type and where the device was installed: V-notch weirs (90º) with a level probe, ultrasonic flow meters and tipping bucket flow gauges. All the details regarding the equipment installed in Xàtiva can be found in Perales-Momparler et al. (2014). The equipment used in Benaguasil is the same as in Xàtiva. Table 2 summarizes all the equipment installed and the output variables.

Site	Device	Monitored variable	Monitoring start date	Monitoring end date
X1	V-notch weir + level probe	Discharge from the basin	27/09/2012	30/09/2013
X2	V-notch weir + level probe	Discharge from the swale	19/09/2012	30/09/2013
X3	Tipping bucket flow meters	Runoff from the green roof and from the conventional roof	18/10/2012	30/09/2013
B1	V-notch weir + level probe	Discharge from the basin	06/11/2012	30/09/2013
B2	Level probe	Volume stored in the tank	30/11/2012	30/09/2013
B3	Ultrasonic flow meter	Discharge from the basin	06/11/2012	30/09/2013

Table 2. *Monitoring of quantity variables (adapted and completed from Perales-Momparler et al. (2014)).*

2.2. Monitoring of water quality variables

In terms of water quality monitoring, ten and six water sampling points were used in Xàtiva and Benaguasil SuDS respectively. Details of sampling points can be found in Table 3 and the sampling procedure is described in Perales-Momparler et al. (2014).

Water was collected using 2 l plastic bottles with one bottle per sampling point per event. Since the bottles filled at the beginning of each rainfall event, the water quality observed corresponded to the first wash off. The bottles at the outlets (points X13, X23, B13 and B22) were filled only if there was discharge. COD, TN and TP were analyzed using a Spectroquant® analysis system by Merck. BOD_5 was measured using OxiTop®. TSS and VSS were determined according to the Standard Methods for examination of water and wastewater (APHA, 1991). Water temperature, pH, conductivity, and DO were measured with WTW® probes in situ.

Regarding statistical analyses, descriptive statistics were calculated and results are displayed by boxplots. Correlation coefficients ($r_{Pearson}$) between water quality variables are also calculated. The influence of meteorological variables (antecedent dry period, rainfall intensity) was analyzed using a multivariate analysis (linear regression with stepwise selection method). The influence of contaminants origin was evaluated by comparing the results from different sampling points using Kruskal-Wallis test (significance level, $p<0.05$). The statistical analyses were performed using the SPSS 16.0 software (SPSS® software).

Site	Description	Id.	N
X1	Inflow 1 from recreational area	X11	11
	Inflow 2 from road with traffic	X12	11
	Outflow to sewer system	X13	7
X2	Inflow 1, from road without traffic	X21	8
	Inflow 2, from road with traffic	X22	11
	Outflow to sewer system	X23	4
X3	Outflow from green roof	X31	9
	Outflow from non-vegetated roof	X32	9
	Atmospheric deposition	X33	5
	Harvesting tank	X34	7
B1	Inflow from road with traffic	B11	8
	Outflow to sewer system	B13	0
B2	Atmospheric deposition	B21	4
	Harvesting tank	B22	5
B3	Inflow from industrial warehouse	B31	6
	Outflow to sewer system	B32	1

Table 3. *Description of monitored sites and sampling points (X: Xàtiva; B: Benaguasil; Id.: identification code; N: number of monitored events).*

3. Monitoring results and discussion

3.1. Rainfall patterns during the monitored period

During the monitoring period, 17 events were recorded in Xàtiva (Table 4) and 19 in Benaguasil (Table 5). This numbers of events per year correspond to a dry period in this Mediterranean region. In Valencia, the average number of events per year for the period 1990-2006 is 27.3 (Andrés-Doménech et al., 2010). The annual average rainfall is 690 mm in Xàtiva and 430 in Benaguasil. During the year monitored, 618 mm were recorded in Xàtiva (-10%) and 373 mm in

Benaguasil (-13%). The most torrential events occurred at the end of the summer and in autumn (event 1 at both locations and event 19 in Benaguasil) even though there were also typical spring showers recorded during the year monitored (events 13 and 15 in Xàtiva and event 14 in Benaguasil). Tables 4 and 5 summarize the key variables of each event recorded: start and end dates, previous inter-event dry period, duration, rainfall depth and maximum 10-min intensity.

Event	Start date	End date	Previous inter-event dry period (days)	Event duration (h)	Event rainfall depth (mm)	Maximum 10-min intensity (mm h^{-1})
1	27/09/2012 15:30	30/09/2012 10:00	28.50	66	92.0	73.2
2	12/10/2012 17:50	13/10/2012 00:40	12.3	7	35.4	48.0
3	19/10/2012 21:50	21/10/2012 12:30	6.9	39	23.8	9.6
4	25/10/2012 05:40	25/10/2012 19:20	3.7	14	5.6	6.0
5	30/10/2012 13:20	31/10/2012 06:10	4.8	17	5.4	3.6
6	09/11/2012 06:20	15/11/2012 17:40	9.0	155	202.8	42.0
7	17/11/2012 21:30	19/11/2012 04:00	2.2	30	8.0	6.0
8	26/11/2012 06:30	27/11/2012 15:20	7.1	33	9.6	6.0
9	25/12/2012 23:10	26/12/2012 06:40	28.3	8	4.6	2.4
10	19/02/2013 12:40	20/02/2013 03:40	55.3	15	5.6	3.6
11	27/02/2013 11:10	01/03/2013 18:40	7.3	56	132.4	21.6
12	04/03/2013 03:30	05/03/2013 22:10	2.4	43	16.8	4.8
13	05/04/2013 12:50	05/04/2013 20:40	30.6	8	29.2	43.2
14	25/04/2013 02:20	29/04/2013 02:20	19.2	96	88.3	10.8
15	14/05/2013 09:30	16/05/2013 03:20	15.3	42	15.4	42.0
16	27/05/2013 15:00	30/05/2013 08:00	11.5	65	4.8	-
17	27/08/2013 17:00	31/08/2013 17:00	89.4	96	30.6	-

Table 4. *Rainfall events recorded in Xàtiva.*

Event	Start date	End date	Previous inter-event dry (days)	Event duration (h)	Event rainfall depth (mm)	Maximum 10-min intensity (mm h^{-1})
1	27/09/2012 06:00	30/09/2012 11:20	-	77	72.0	62.4
2	12/10/2012 15:20	14/10/2012 23:50	12.2	56	7.4	6.0
3	19/10/2012 22:40	21/10/2012 04:30	5.0	30	55.2	58.8
4	25/10/2012 05:50	26/10/2012 06:30	4.1	25	5.4	2.4
5	30/10/2012 14:40	30/10/2012 22:20	4.3	8	4.0	3.6
6	09/11/2012 03:10	09/11/2012 22:30	9.2	19	6.0	14.4
7	11/11/2012 14:00	11/11/2012 22:50	1.6	9	4.2	3.6
8	13/11/2012 13:20	13/11/2012 21:10	1.6	8	4.4	9.6
9	17/11/2012 08:10	18/11/2012 16:30	3.5	32	10.6	12.0
10	24/01/2013 09:50	24/01/2013 13:30	66.7	4	1.8	8.4
11	28/02/2013 00:40	01/03/2013 12:20	34.5	36	13.0	4.8
12	04/03/2013 18:10	05/03/2013 22:22	3.2	28	30.2	6.0
13	05/04/2013 14:30	05/04/2013 18:20	30.7	4	11.0	10.8
14	25/04/2013 05:10	30/04/2013 23:50	19.5	139	78.2	39.6
15	14/05/2013 05:00	15/05/2013 15:00	13.2	34	8.2	4.8
16	30/05/2013 01:40	30/05/2013 03:40	14.4	2	3.4	2.4
17	21/06/2013 19:40	21/06/2013 21:20	22.7	2	4.8	10.8
18	09/07/2013 19:40	10/07/2013 23:50	17.9	28	8.0	19.2
19	26/08/2013 01:30	30/08/2013 07:10	46.1	102	45.2	48.0

Table 5. *Rainfall events recorded in Benaguasil.*

3.2. Hydraulic performance

The hydraulic performance of each pilot site was analyzed against rainfall events of different magnitude. In Xàtiva, sites X1 and X2 were able to cope with all the runoff generated in the events which had a total depth of 25 mm or less. In events of greater magnitude, the volume draining to the sewer network was significantly reduced with volumetric efficiencies always greater than 65% (Table 6). The antecedent dry period also affects the hydraulic performance of the site. Events 2, 13 and 17 had very similar rainfall depths: 35.4, 29.2 and 30.6 mm respectively. Nevertheless, all events except 17 produced overflow. Its antecedent dry period was almost 3 months, whereas for events 2 and 13 there were only 12 and 31 previous dry days respectively.

Event	Event rainfall depth (mm)	X1 – Infiltration basin		X2 – Roadside swale	
		Spilled volume (mm)	Volumetric efficiency (%)	Spilled volume (mm)	Volumetric efficiency (%)
1	92.0	15.1	84	16.4	82
2	35.4	4.2	88	4.8	86
3	23.8	0	100	0	100
4	5.6	0	100	0	100
5	5.4	0	100	0	100
6	202.8	33.4	84	18.8	91
7	8.0	0	100	2.6	68
8	9.6	0	100	0	100
9	4.6	0	100	0	100
10	5.6	0	100	0	100
11	132.4	n/a	n/a	6.8	95
12	16.8	0	100	0	100
13	29.2	1.5	95	0.2	99
14	88.3	32.0	64	0.9	99
15	15.4	0	100	0	100
16	4.8	n/a	n/a	n/a	n/a
17	30.6	0	100	0	100

Table 6. *Hydraulic efficiency of pilots X1 and X2.*

The runoff produced from the green and conventional roofs at site X3 were compared. Due to operational problems with the green roof tipping bucket system, comparable monitoring results were only available for event 8 (Table 7). Additional failures of the monitoring system also occurred later (events 11, 12, 15 and 16).

Event	Event rainfall depth (mm)	X3 – Conventional roof		X3 – Green roof	
		Spilled volume (mm)	Volumetric efficiency (%)	Spilled volume (mm)	Volumetric efficiency (%)
8	9.6	5.3	45	4.5	53
9	4.6	3.2	30	1.2	74
10	5.6	2.6	54	0.0	100
11	132.4	n/a	n/a	n/a	n/a
12	16.8	13.5	20	n/a	n/a
13	29.2	21.6	26	4.0	86
14	88.3	60.7	31	17.7	80
15	15.4	n/a	n/a	n/a	n/a
16	4.8	n/a	n/a	n/a	n/a
17	30.6	28.2	8	13.9	55

Table 7. *Hydraulic efficiency in site X3. Comparison between the green roof and the conventional roof.*

During the start-up period of the green roof, irrigation reduced significantly its hydraulic efficiency (Perales-Momparler et al., 2014). Nevertheless, even though irrigation was carried out to ensure the proper development of the vegetation, volumetric efficiencies of up to 50% were achieved at the green roof. When irrigation operations were less frequent (winter and spring, events 10, 13, 14), the volumetric efficiency rose. However, when event 17 occurred at the end of the summer and after 3 months without rainfall, the green roof was again being irrigated, so the efficiency for this last recorded event fell to 55%. These results highlight the impact of irrigation on the green roof performance, and the importance of planting with vegetation with a very low water demand.

Time delays and peak flow reductions were observed between the start of discharge from the green roof and from the conventional roof. Fig. 2 shows the hydraulic behavior of both roofs during a typical short torrential shower recorded in April 2013. The total rainfall volume was 29 mm and the maximum 10-minute intensity was 43 mm/h. Only 26% of the rainfall volume was detained by the conventional roof whereas 86% efficiency was achieved in the green roof. Peak flow reduction is also significant. As it can be observed, the conventional runoff was seven times greater than from the green roof.

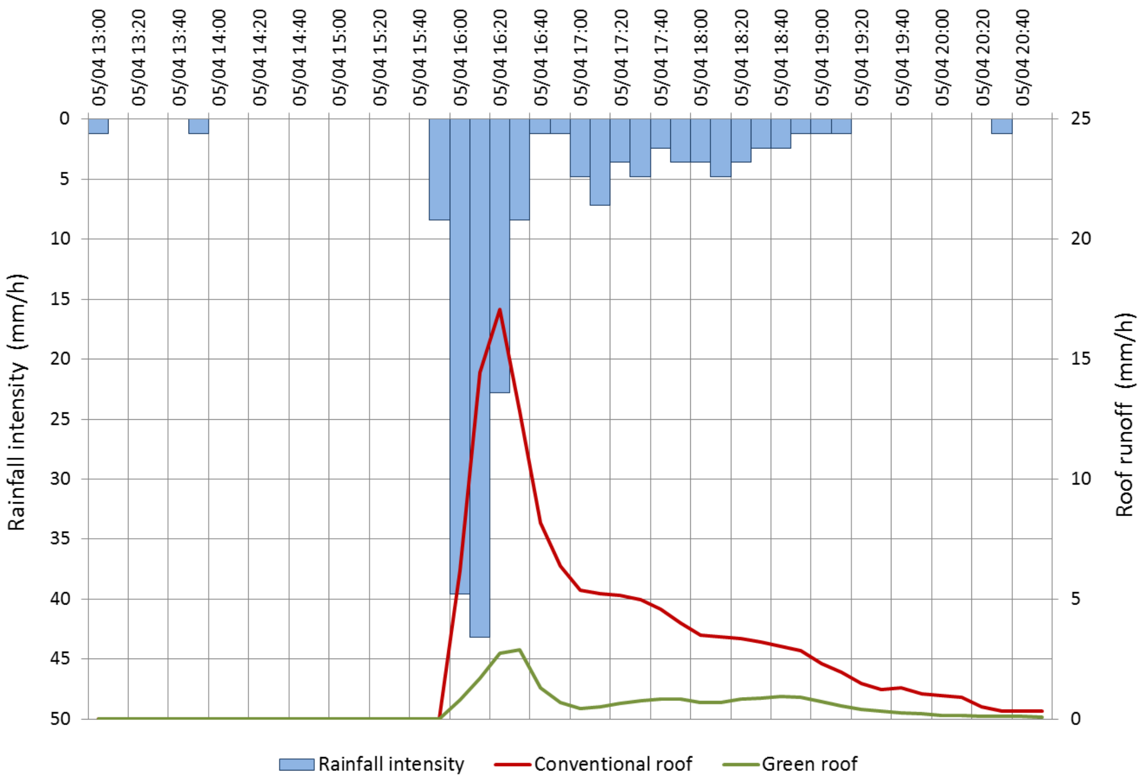


Fig. 2. *Comparison between the green roof and the conventional roof runoff during rainfall event 13 (5th April 2013).*

In Benaguasil, the infiltration basin at the industrial estate (B3) coped with the runoff generated from every event and no discharge from this site was observed. The detention basins at Costa Ermita (B1) were similarly efficient and runoff spilled to the downstream sewer system only once during the whole period (event 1).

The rainwater tank collected water during all storm events to be used later to irrigate the adjacent park. Pumping is not required because the park is at a lower level giving water and energy savings. Fig. 3 shows the stored volume during the monitoring period. In May 2013, the level probe failed and the tank was partially emptied for maintenance. During the summer, almost 2.5 m^3 of water were reused for irrigation.

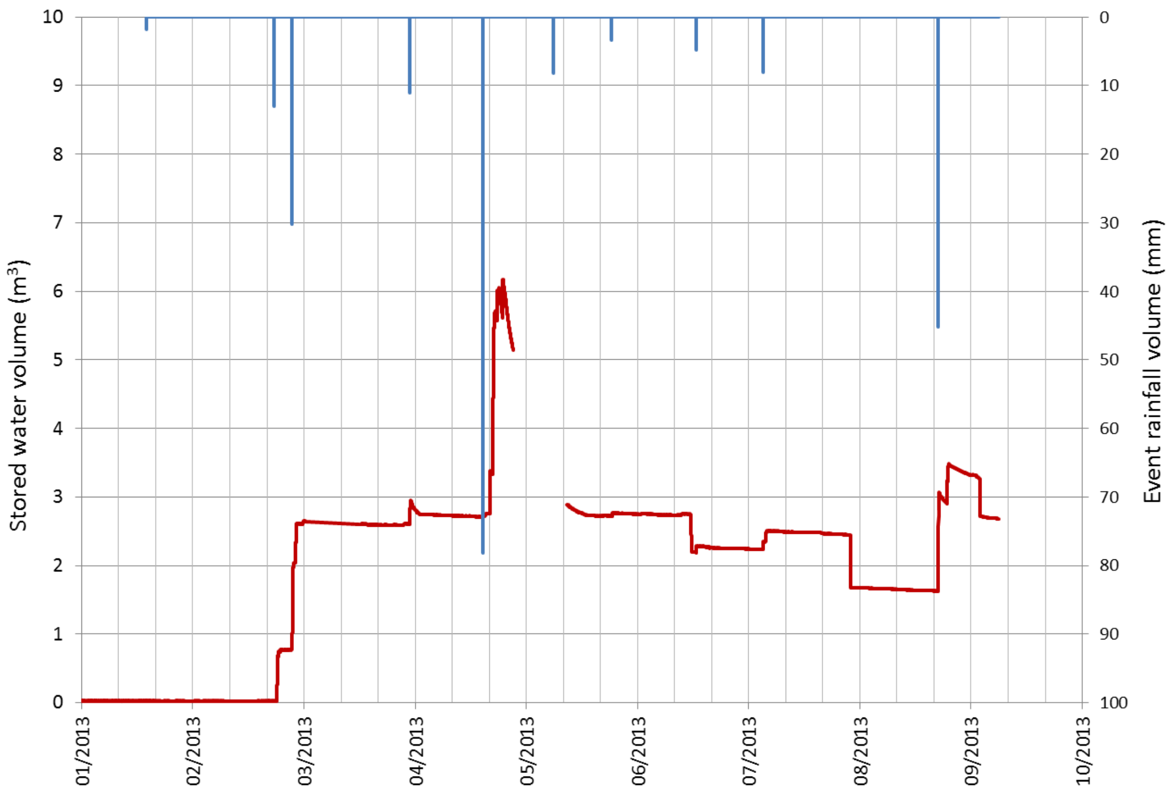


Fig. 3. *Stored water volume at the rainwater harvesting tank.*

3.3. Water quality results

The water quality results indicate that runoff from roadways (X12 in Xàtiva Sports City and X22 in North Ring Road) do not differ significantly from each other ($p>0.05$) but they are more contaminated than the other inlets (X11 and X21) (Fig. 4). For example, the concentration of organic matter is high and highly variable, ranging between 72 and 1600 $mg \cdot L^{-1}$ (Fig. 4). COD is strongly linearly correlated with TSS ($r^2_{Pearson} = 0.76$) and VSS ($r^2_{Pearson} = 0.80$). TP is also correlated with TSS ($r^2_{Pearson} = 0.70$) because of the sorption processes involving both variables (Kadlec and Wallace, 2009). However, as expected, no correlation was found between TN and TSS because the dissolved species of nitrogen (ammonia and nitrates) have low sorption capacity. All the water quality concentrations reduced in the swales between inlet and outlet showing the effectiveness of this system: the poorest performance was for TSS (35%) whereas the best was for TN with a 60% concentration reduction.

It is known that antecedent dry period, storm intensity and traffic density are relevant factors influencing the runoff quality (Kim et al., 2006; Brodie and Dunn, 2010; Zuo et al., 2011). No significant differences were found between water quality variables in X12 and X22 ($p>0.05$), so all the values obtained from both roads were used in a multivariate analysis which showed that antecedent dry period was the most significant variable for TP and TN whereas rainfall intensity was the most influential for COD and TSS. In fact, some values of TSS were much higher (more than 1 000 mg·L^{-1}) than maximum observed in other studies under different climatic conditions (Stagge et al, 2012).

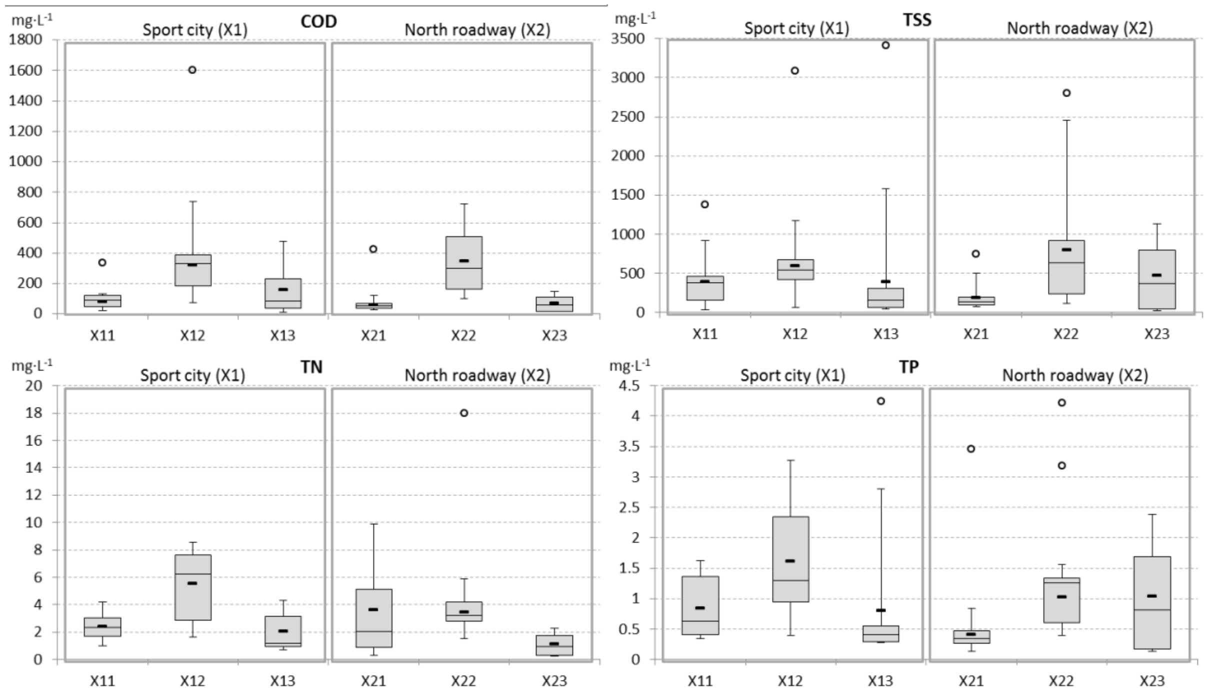


Fig. 4. *Water quality variables of runoff at sites X1 and X2.*

The influence of traffic can be seen from a comparison between sites with different source of pollutants (X11: recreational area, X21: residential/low traffic area, and X12-X22 roadways with intense traffic). The statistical analysis reveals significantly higher ($p<0.05$) levels of COD, TSS and TP in runoff from roadways with traffic. For instance, COD from X22 is six times higher than X21 (Fig. 4), showing the presence of hydrocarbons, plastics, etc. from vehicles. In contrast, TN concentration does not differ significantly between roadways with high and low traffic, a fact that may be related to the greater mobility of nitrogen compounds. On the other hand, runoff from the recreational area (X11) had lower concentrations of COD and TN than the roadways ($p<0.05$) but similar levels of TSS and TP ($p>0.05$), probably due to soil erosion from gardens, especially during very intense rainfall events.

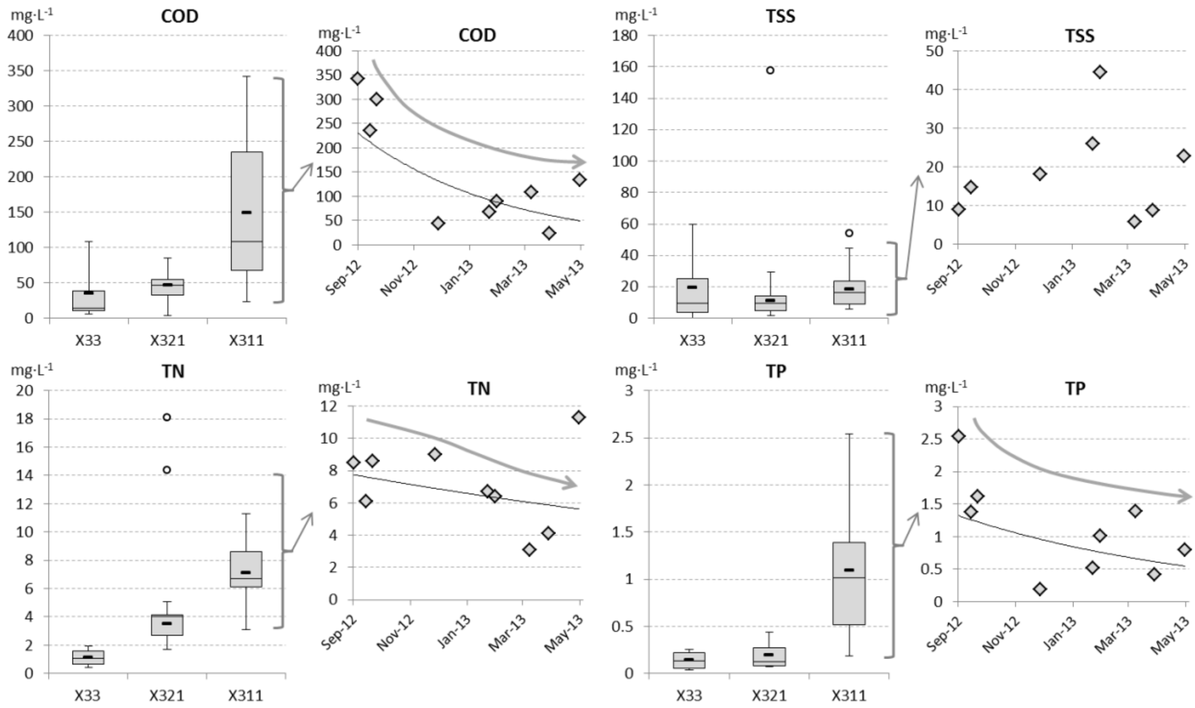


Fig. 5. *Water quality variables of runoff in site X3 (X33: rainwater; X32: conventional roof; X33: green roof).*

With regard to the green roof results, box-plots of COD, TSS, TN and TP are shown in Fig. 5. The comparison between the water quality data from the green roof (X311) and the non-vegetated roof (X321) in the start-up period clearly shows the green roof in a poor light, except for TSS which was usually below 20 mg·L^{-1}. There were no significant differences between rain water (X33) and roof water ($p>0.05$). However, nutrients (TN and TP) and organic matter (COD) were notably higher in runoff from the green roof ($p<0.05$), showing the washing of dissolved substances. This washing effect declined after some time: for instance, COD concentrations decreased from values higher than 350 mg·L^{-1} to 50 mg·L^{-1} and similar trends are observed for TN and TP (see temporal evolution of X31 in Fig. 5). After 17 rainfall events (total volume drained 9.0 m^3 according to Table 7), TN and TP concentrations were reduced by approximately one half, a decrease also observed by Malcolm et al. (2014). Nevertheless, in spite of presenting higher concentrations of COD and nutrients, supposing this concentration constant (worst case scenario), the total loads drained by the green roof are lower than that drained by the non-vegetated roof, because of the higher volumetric efficiency of green roof. The roof material was a specific green roof substrate with high content of organic matter and nutrients added to ensure the plant growing. The ideal situation for a green roof is one in which nutrients and humidity supplied by atmospheric deposition (wet and dry) are enough to maintain the vegetation and the soil microorganism activity; the role of a well-developed green roof as trap of pollutants could be relevant in this case. But one of the uncertainties in the use of these infrastructures in Mediterranean climate is related with the intensity and rainfall intervals: if there is a heavy rainfall event, nutrients previously settled by dry deposition will be quickly washed, so a pool of nutrients is necessary inside the substrate, at least until the vegetation raises its maturity. In any case, the ability of green roof to improve the water quality from rainfall is still matter of debate (Rowe, 2011). Nevertheless there are many reasons to encourage the installation of green roof such as a greater energy efficiency, aesthetics, improvement to city climate, biodiversity enhancement, all these improving the quality of city life (Berndtsson et al. 2006).

In Benaguasil, infiltration basins in B1 registered only one spill in the whole period showing their ability to reduce not only flow discharges to sewer system but the pollutant mass loading. These basins receive high load of TSS and particle-bounded pollutants (Table 8) from the erosion of soil. The proximity of a big forested zone upstream influences the quality of runoff with the highest TN and TSS mean concentration of all sites. These basins play a very important role in pollutants sequestration because of their 100% volumetric efficiency. This in turn reduces the loads from sewer system to local waste water treatment plant and/or discharges to the receiving water body, contributing to an improvement of sewage treatment facilities and also of river ecosystem.

In contrast, the washing of roofs and pavement of industrial estate (B3 in Table 8) provide runoff concentrations lower than Costa Ermita (B1), showing high differences depending on the different characteristics of catchment areas.

All sampling sites, both in Xàtiva and Benaguasil, share the common characteristic of a poorly biodegradable organic matter, with relationship BOD_5/COD lower than 0.22.

Water quality variable	B1	B3	B22	X34
COD ($mg \cdot L^{-1}$)	1158 ± 622	152 ± 155		
BOD_5 ($mg \cdot L^{-1}$)	63 ± 50	34 ± 28		
TN ($mg \cdot L^{-1}$)	13,49 ± 7,00	4,02 ± 3,29		
TP ($mg \cdot L^{-1}$)	2,49 ± 1,88	0,47 ± 0,44		
TSS ($mg \cdot L^{-1}$)	2252 ± 1349	84 ± 90		
VSS ($mg \cdot L^{-1}$)	330 ± 163	23 ± 20		
Turbidity (NTU)	1325 ± 962	135 ± 184		
Conductivity ($\mu S \cdot cm^{-1}$)	377 ± 262	198 ± 90	246 ± 50	44 ± 6
Temperature (ºC)	16,0 ± 6,3	16,6 ± 5,9	21,6 ± 2,4	21,4 ± 3,2
pH	7,60 ± 0,31	6,88 ± 0,32	7,48 ± 0,58	6,97 ± 0,58
DO ($mg \cdot L^{-1}$)	5,98 ± 3,47	5,96 ± 3,77	7,58 ± 2,04	8,36 ± 0,84
% Sat DO	57% ± 29%	58% ± 32%	85% ± 20%	94% ± 7%
Escherichia Coli (CFU/100 mL)			2 ± 4	8 ± 11
Intestinal nematodes (egg/10 L)			<1	<1

Table 8. *Mean and standard deviation of quality variables at sampling points in Infiltration-detention basins B1 and B3 and harvesting tanks in Benaguasil (B22) and Xàtiva (X34).*

The last showcases are the harvesting tanks in Benaguasil (B22) and Xàtiva (X34). The tanks collected rain water that could be used for irrigation in green zones because microbiology indicators, Escherichia coli and intestinal nematodes (Table 8), were below the most limiting values of the Spanish water reuse law (R.D.1620/2007: 100 CFU/100 mL for Escherichia coli and 1 egg/10 L for intestinal nematodes). Despite the fact that this regulation only concerns treated wastewater, it is commonly used for reference values.

3.4. Overall assessment of the data

The data show that the pilots SuDS have good hydraulic performance under typical Mediterranean climate. One of the most important barriers for their implementation in this area was the lack of local experience and the uncertainty on their performance. The results show that SuDS are also suitable and reliable under a climate with small rainfall totals but with torrential events. Overall the volumetric hydraulic performances achieved were quite high with retention very close to 100% except for the green roof. Peak flow control is also important and rainwater harvesting and reuse has also been shown as plausible with the pilots.

From the standpoint of water quality, the study has allowed the degree of pollution to be distinguished between three types of urban surface: roofs, gardens and roadways. The latter generate much higher concentrations of organic matter (up to 1 600 $mg \cdot L^{-1}$ of COD) and suspended solids (up to 3 083 $mg \cdot L^{-1}$ SST), reflecting the influence of traffic. The fact that in any event runoff from gardens is similar to that of the road is due to torrential rainfall and its erosive power, characteristics typical of Mediterranean climates. Conversely, the differences between the types of urban surfaces are not so clear for total nitrogen, for which the values are around 4 $mg \cdot L^{-1}$, revealing the importance of atmospheric deposition in this variable.

Results show that the grass swales and infiltration basins improve water quality before it is discharged to the sewer system (maximum COD discharged of 478 $mg \cdot L^{-1}$) although this improvement is irregular depending on the hydraulic retention time. This quality improvement is sufficient to meet discharge municipal ordinances (e.g. COD lower than 1 000 $mg \cdot L^{-1}$, typical value of discharge requirement) and to ensure the proper functioning of the waste water treatment plant (WWTP), thus minimizing impacts on the receiving waterbody. Consequently, an important part of the contaminated load is retained and naturally treated by the SuDS infrastructures, so polluted loads discharged to the sewer system or any receiving water body are significantly reduced.

However, the efficiency of these systems should not be measured only in terms of the reduction in pollutant concentration but also in the reduction of total load spilled. Data gathered from site X3 is a good example of this: although runoff from the vegetated part (green roof) has higher pollutant concentrations than its non-vegetated counterpart, less runoff volume is discharged, resulting in less total pollution leaving the site.

Furthermore the presence of SuDS attenuates the peak of the pollution load entering a WWTP thus helping to reduce any impact on its proper operation. This improvement of WWTP operation achieved by SuDS could also be achieved by building storm tanks at the WWTP inlet; it is likely that the construction and operation costs associated with the pumping and treatment of the stored water would be higher and a tank cannot provide any community or biodiversity benefits.

Removing invasive vegetation and replacement of a small number of dead plants have been the main maintenance operations on the green roof (2-3 times per year). Sediment, washed from higher up its catchment, has had to be removed from site B3 after each storm. Sediments from the hill also accumulate in site B1 although removal is expected to be required only every 5 years. In both cases, SuDS prevent those sediments from entering the sewer network from where removal would be much more difficult and expensive. For the rest of the sites, only regular vegetation management and trash removal has been required to date (three years after construction), with visual inspections confirming the good performance of inlets, outlets and the complete infiltration of water shortly after rainfall. All sites were spray irrigated for the first 2-3 years after planting to help their establishment. As the plants used are drought tolerant, it is expected that they will need little additional water from now on, except during prolonged droughts.

Lessons learned through the construction, monitoring, operation and maintenance of the showcase sites will form the basis for future developments in the process of the paradigm shift leading to a broader uptake of SuDS in Spain.

As a very practical example, monitoring results from the green roof retrofitted in Xàtiva guided the design and operation of a green roof retrofitted later in Benaguasil as part of another EU funded project, E^2STORMED (1C-MED12-14, www.e2stormed.eu). For instance, in order to minimize the leaching of nutrients, the substrate composition used in this second green roof was different: with soil of lower nutrient content and the use of controlled release fertilizers. In terms of operation, irrigation is now controlled by the soil moisture and vegetation water demand instead of being periodically activated. The Benaguasil green roof is currently being monitored for its hydrology coupled with energy consumption observations (Alfonso et al., 2015).

4. Stakeholders perceptions on showcases as transition catalyzers

The transition to more sustainable stormwater management is a slow process that requires a wide perspective and the participation of different stakeholders, in which the contribution that science and research are continuously providing is precious (Barbosa et al., 2012).

Within the framework of the AQUAVAL project, a Regional Working Group was created (led by Xàtiva and Benaguasil City Councils) involving actors from across the region in the water sector, public and private. As explained in Perales-Momparler et al. (2015), this group evolved and had continuity within the E^2STORMED project. The total number of actors was downsized to allow for productive dialogue, although incorporating key stakeholders on environment, urban planning and the energy sector with represented at political, technical and managerial levels. These stakeholders had the opportunity to visit the showcase sites and were presented with monitoring results as they became available. Their perceptions were informally collected and considered for future actions such as the development of a Strategic Action Plan for Benaguasil.

Regional Working Group members highlighted the importance of demonstration projects as catalyzers of the transition, in particular when monitoring results are presented in an understandable way for decision makers. The AQUAVAL showcase sites have influenced not only local practice, but more important, the support for SuDS in recent regional legislation which dictates that the use of SuDS must be encouraged in all municipalities of the Valencian region (Resolution of 31st October 2013). In this piece of legislation, the Valencian Regional Government presents Benaguasil and Xàtiva showcases as a model to be followed. It is also worth highlighting the role of the Valencia City Council (Diputación de Valencia), that being a member of the Regional Working Group, actively disseminates the E^2STORMED project events and outcomes using the "Valencian municipalities towards sustainability network" website (i.e. http://www.dival.es/xarcia/content/sistemas-de -drenaje-sostenible-en-benaguasil-proyecto-europeo-e2stormed).

In addition, in order to survey the importance given by stakeholders to demonstration activities, a questionnaire was distributed amongst participants on a national workshop on sustainable urban drainage held in Valencia in April 2015 within the framework of the E^2STORMED project. For this survey 6 questions were analyzed: two related to stakeholders' classification (age group and professional affiliation), three to provide their agreement level (completely agree, agree, neutral, disagree and completely disagree) on the importance of demonstration activities (pilot construction, water quantity monitoring and water quality monitoring), and one to choose the single most important activity amongst the latter. For this last question, two additional choices were added: the possibility to have a decision making tool available or none of the above. Questionnaires were distributed electronically few days after the workshop to the 79 attendees.

The questionnaire responses demonstrate the relevance of showcases in a similar way to the ones presented herein. A high response was achieved (44%), with respondents belonging to 10 professional affiliations (23% local government professional; 20% consultant; 20% researcher/academic; 14% water utility; 3% regional government professional; 3% national government professional, 3% tradesman; 3% manufacturer; 3% student; 8% others) and from all age group categories (3% 18-24; 17% 25-34; 46% 35-44; 29% 45-54; 6% 55-64).

Responders highly agreed on the importance of demonstration activities. When asked about how much they agreed on the importance of constructing demonstration sites, 89% completely agreed and 9 % agreed. This positivism was repeated, although not as forcefully when asked about the importance of water quantity and quality monitoring activities. In both cases, 66% completely agreed and 31% agreed. When asked to choose the most important demonstration activity, 57% opted for pilot construction, 11% quantity monitoring and 9 % quality monitoring.

At this point it is worth recalling that SuDS provide collective benefits (flood protection, water quality, landscaping, etc.), require collective efforts and challenge the traditional means of stormwater governance, all this making the interaction of stakeholders fundamental.

In other words, poor interaction between stakeholders is incompatible with such enhanced or smarter governance which is by itself also a form of innovation in addition to the innovation brought by means of new constructions and technologies. The way stakeholders have been engaged and how their understanding of the showcase sites as transition catalyzers was assessed, smooths the difficulties that innovation faces in being presented, understood, and endorsed by professionals and decision-makers.

The result is that SuDS are now perceived as a realistic storm water management alternative for both retrofitting and new urban developments in the Valencian region.

5. Conclusions

This paper addresses the issue of providing scientific knowledge and practical approaches to counteract a number of undesired effects of existing and planned urbanization related to the impervious surfaces generated (buildings, roads, parking lots, etc.).

SuDS, as ecological urban infrastructures, bring together technologies, engineering and governance, helping in the management of aspects of storm water quantity and quality in a comprehensive and sustainable manner while adding multiple additional benefits.

Although SuDS are key piece in the transition towards regenerative urban built environments, there is still limited evidence on the performance of these systems and a need of quantifying their acknowledged benefits, i.e. in terms of flood protection and water quality among others.

In this context, the six showcase sites presented herein provide proof of concept in the field both in the quantitative and qualitative phases of the performance of SuDS as well as providing compelling examples of how this new knowledge enhances storm water governance. Furthermore, the engagement of stakeholders in their development has confirmed the strategic importance of the construction and monitoring of demonstration sites.

Examples of the current and potential impact of the knowledge generated are their influence in the legislative support given by the Valencian Regional Government to SuDS and the suitability of the data collected to calibrate models (e.g. of green roof efficiency in attenuating the storm peak) which could later be used to assess larger scale SuDS retrofitting agendas.

Beyond all the detailed benefits of the demonstration sites monitored, in a broad sense, they have been drivers of innovation and formed the basis of a new storm water paradigm in a Spanish region which will certainly benefit from it in the near future, serving as a reference to other urban areas in the Mediterranean.

Acknowledgements

This research has been conducted as part of the Life+ program project "AQUAVAL: Sustainable Urban Water Management Plans, promoting SUDS and considering climate change, in the province of Valencia" (Life08ENV/E/000099) and the MED program project "E^{2}STORMED: Improvement of energy efficiency in the water cycle by the use of innovative storm water management in smart Mediterranean cities" (1C-MED12-14), both supported by European Regional Development Fund (ERDF) funding of the European Union.

References

Alfonso, D., Peñalvo, E., Pérez-Navarro, A., Valencia, I., 2015. Energy efficiency effects of green roofs in buildings. An experimental assessment for Mediterranean areas. Proceedings of the IWRA World Water Congress XV, Edinburgh, Scotland.

Anderson, J., Iyaduri, R., 2003. Integrated urban water planning: big picture planning is good for the wallet and the environment. Water Science and Technology : a Journal of the International Association on Water Pollution Research, 47, 7-8, 19-23.

Andrés-Doménech, I., Montanari, A., Marco, J. B., 2010. Stochastic rainfall analysis for storm tank performance evaluation. Hydrol. Earth Syst. Sci., 14, 1221-1232. http://dx.doi.org/10.5194/hess-14-1221-2010.

APHA , Standard methods for the examination of water and wastewater, 1991. 17th ed., American Publish Health Associaton. Washington, DC (USA).

Arnbjerg-Nielsen, K., Willems, P., Olsson, J., Beecham, S., Pathirana, A., Bülow, G.I., Madsen, H., Nguyen, V.T.V., 2013. Impacts of climate change on rainfall extremes and urban drainage systems: a review. Water Sci. Technol. 68 (1), 16–28. http://dx.doi.org/10.2166/wst.2013.251.

Barbosa, A.E., Fernandes, J.N., David, L.M., 2012. Key issues for sustainable urban stormwater management. J. Wat. Res. 46, 6787-6798. http://dx.doi.org/10.1016/j.watres.2012.05.029.

Berndtsson, J.C., Emilsson, T., Bengtsson, L., 2006. The influence of extensive vegetated roofs on runoff water quality. Sci. Tot. Environ. 355, 48-63. http://dx.doi.org/10.1016/j.scitotenv.2005.02.035.

Binney, P., Donald, A., Elmer, V., Ewert, J., Phillis, O., Skinner, R., Young, R., 2010. IWA Cities of the Future Program. Spatial Planning and Institutional Reform Discussion Paper for the World Water Congress. Spatial Planning and Institutional Reform Working Group Report, Montreal, Canada. http://www.iwahq.org/contentsuite/upload/iwa/document/updated%20iwa%20spatial%20planning%20and%20institutional%20reform%20group%20montreal%20discussion%20paper.pdf (accessed 01.06.15).

Broodie, I.M., Dunn, P.K., 2010. Commonality of Rainfall Variables Influencing Suspended Solids Concentrations in Storm Runoff from Three Different Urban Impervious Surfaces, J. Hydrol. 387, 202-211. http://dx.doi.org/10.1016/j.jhydrol.2010.04.008.

Brown, R.R., Farrelly, M.A., 2009. Delivering sustainable urban water management: a review of the hurdles we face. Water Sci. Technol. 59 (5), 839e846. http://dx.doi.org/10.2166/wst.2009.028.

Brown, R.R., Keath, N., Wong, T.H.F., 2009. Urban water management in cities: historical, current and future regimes. Water Sci. Technol. 59, 5, 847-855. http://dx.doi.org/10.2166/wst.2009.029.

Burns, M.J., Fletcher, T.D., Walsh, C.J., Ladson, A.R., Hatt, B.E., 2012. Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. Land. Urb. Plan. 105, 230-240. http://dx.doi.org/10.1016/j.landurbplan.2011.12.012.

Casal-Campos, A., Jefferies, C., Perales-Momparler, S., 2012. Selecting SUDS in the valencian region of Spain. Water Pract. Technol. 7, 1. http://dx.doi.org/10.2166/wpt2012.001 (published online).

Castro-Fresno, D., Andrés-Valeri, V. C., Sañudo-Fontaneda, L. A., Rodríguez-Hernández, J., 2013. Sustainable drainage practices in Spain, specially focused on pervious pavements, Water, 5, 67-93. http://dx.doi.org/10.3390/w5010067.

Charlesworth, S.M., 2010. A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. Journal of Water and Climate Change, 1, 3, 165-180. http://dx.doi.org/10.2166/wcc.2010.035

Charlesworth, S.M., Perales-Momparler, S., Lashford, C., Warwick, F., 2013. The sustainable management of surface water at the building scale: preliminary results of case studies in the UK and Spain. J. Water Supply Res. Technol. 62 (8), 534-544. http://dx.doi.org/10.2166/aqua.2013.051.

Chouli, E., Aftiasb, E., Deutscha, J.C., 2007. Applying storm water management in Greek cities: learning from the European experience. Desalination 210, 61e68. http://dx.doi.org/10.1016/j.desal.2006.05.033.

du Plessis, C., 2012. Towards a regenerative paradigm for the built environment. Building Research & Information, 40, 1, 7-22. http://dx.doi.org/10.1080/09613218.2012.628548

European Commission, 2010. Toledo reference document on integrated urban regeneration and its strategic potential for a smarter, more sustainable and socially inclusive urban development in Europe. Toledo, *22 June 2010. Last accessed 24-April-2015 from http://ec.europa.eu/regional_policy/archive/newsroom/pdf/201006_toledo_declaration_en.pdf.*

Frantzeskaki, N., Loorbach, D., Meadowcroft, J., 2012. Governing societal transitions to sustainability: Transition management as a governance approach towards pursuing sustainability. Int. J. Sustainable Development, 15, 1-2, 19-36.

Halpin, E., Escuder, I., 2015. Smart governance of infrastructure programs: facing the next generation of challenges and succeeding. Proceedings of the 25 ICOLD Congress. Norway.

Hunt, D.V.L., Rogers, C.D.F., 2005. Barriers to sustainable infrastructure in urban regeneration. Engineering Sustainability, 158, 2, 67-81.

Jefferies C., Duffy A.M., 2011. The SWITCH Transition Manual. ISBN 978-1-899796-23-6. http://www.switchurbanwater.eu/outputs/pdfs/W1-3_GEN_MAN_D1.3.4_SWITCH_Transition_Manual.pdf (accessed 01.06.15).

Jim, C.Y., 2004. Green-space preservation and allocation for sustainable greening of compact cities. Cities, 21, 4, 311–320. http://dx.doi.org/10.1016/j.cities.2004.04.004.

Kadlec, R.H., Wallace, S.C., 2009. Treatment Wetlands (2nd. Edition). CRC Press. Taylor & Francis Group. ISBN 978-1-56670-526-4.

Kim, L.H., Zoh, K.D., Jeong, S.M., Kayhanian, M., Stenstrom, M. K., 2006. Estimating Pollutant Mass Accumulation on Highways during Dry Periods, J. Environ. Eng. 132, 985-993. http://dx.doi.org/10.1061/(ASCE)0733-9372(2006)132:9(985).

Lamera, C., Becciu, G., Rulli, M.C., Rosso, R., 2014. Green roofs effects on the urban water cycle components. J. Pro. Eng. 70, 988-997. http://dx.doi.org/10.1016/j.proeng.2014.02.110.

Li, F., Wang, R., Paulussen, J., Liub, X., 2005. Comprehensive concept planning of urban greening based on ecological principles: a case study in Beijing, China. Landscape and Urban Planning 72, 325–336. http://dx.doi.org/10.1016/j.landurbplan.2004.04.002

Loorbach, D., Rotmans, J., 2010. The practice of transition management: Examples and lessons from four distinct cases. Futures 42, 237–246. http://dx.doi.org/10.1016/j.futures.2009.11.009.

Loorbach, D., van Bakel, J. C., Whiteman, G., & Rotmans, J. 2010. Business strategies for transitions towards sustainable systems. Business Strategy and the Environment, 19, 2, 133-146. http://dx.doi.org/10.1002/bse.645.

Malcolm, E.G., Reese, M.L., Schaus, M.H., Ozmon, I.M., Tran, L.M., 2014. Measurements of nutrients and mercury in green roof and gravel roof runoff. Ecol. Eng. 73, 705-712. http://dx.doi.org/10.1016/j.ecoleng.2014.09.030.

Millán, P., Nácher-Rodríguez, B., Hernández, C., Martín, M., Vallés, F.J., Andrés-Doménech, I., Perales-Momparler, S., 2013. Comparative analysis of runoff from a permeable pavement and from a conventional road. In: Vallés-Morán, F.J., Andrés-Doménech, I., Escuder-Bueno, I., López-Jiménez, P.A., Marco, J.B. (Eds.), *2013, III Jornadas de Ingeniería del Agua, La protección contra los riesgos hídricos, vol. 2, ISBN 978-84-267-2071-9, pp. 131-138 (in Spanish).*

Nevens, F., Frantzeskaki, N., Gorissen, L., Loorbach, D., 2013. Urban transition labs: co-creating transformative action for sustainable cities. J. Clean. Prod. 50, 111e122. http://dx.doi.org/10.1016/j.jclepro.2012.12.001.

Norton, B.A., Coutts, A.M., Harris, R.J., Hunter, A.M., Williams, N.S.G., 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning 134, 127-138. http://dx.doi.org/10.1016/j.landurbplan.2014.10.018.

Novotny, V., Ahern, J., Brown, P., 2010. Water centric sustainable communities: planning, retrofitting, and building the next urban environment. John Wiley & Sons, Inc. New Jersey. ISBN 978-0-470-47608-6 .

Pahl-Wostl, C., Tabara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E., Ridder, D., Taillieu, T., 2008. The importance of social learning and culture for sustainable water management. Ecol. Econ. 64,33, 484e495. http://dx.doi.org/10.1016/j.ecolecon.2007.08.007.

Perales-Momparler, S., Andrés-Doménech, I., Andreu, J., Escuder-Bueno, I., in press. A regenerative urban stormwater management methodology: the journey of a Mediterranean city. Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.02.039.

Perales-Momparler, S., Hernández-Crespo, C., Vallés-Morán, F., Martín, M., Andrés-Doménech, I., Andreu Á., J., Jefferies, C., 2014. SuDS Efficiency during the Start-Up Period under Mediterranean Climatic Conditions. Clean-Soil Air Water 42, 2, 178–186. http://dx.doi.org/10.1002/clen.201300164.

Perales-Momparler, S., Jefferies, C., Perigüell-Ortega, E., Peris-García, P.P., Muñoz-Bonet, J.L., 2013. Inner-city SUDS retrofitted sites to promote sustainable stormwater management in the Mediterranean region of Valencia: AQUAVAL (Life+ EU Programme). NOVATECH Conference, Lyon, France.

Potter, K., Ward, S., Shaw, D., Macdonald, N., White, I., Fischer, T., Butler, D., Kellagher, R., 2011. Engineers and planners: sustainable water management alliances. Eng. Sustain. 164 (ES4), 239-247. http://dx.doi.org/10.1680/ensu.2011.164.4.239.

Radywyl, N., Biggs, C., 2013. Reclaiming the commons for urban transformation. J. Clean. Prod. 50, 159-170. http://dx.doi.org/10.1016/j.jclepro.2012.12.020.

Royal Decree 1620/2007 of 7th December establishing the juridic regime for treated water reuse. Boletín Oficial del Estado 294, 2007, 50639-50661 (in Spanish).

Reed, M.S., 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation, 141, 2417-2431. http://dx.doi.org/10.1016/j.biocon.2008.07.014.

Resolution of 31st October 2013, of the Infrastructure, Territory and Environment Regional Ministry, submitting to public information the revision of the Territorial Action Plan on Flood Risk prevention for the Valencian Region. Diario Oficial de la Comunidad Valenciana 7159, 2013, 34289-34290 (in Spanish).

Rowe, D.B., 2011. Green Roofs as a Means of Pollution Abatement. Environ. Pollut, 159, 2100–2110. http://dx.doi.org/10.1016/j.envpol.2010.10.029.

Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Research Policy, 41, 1025-1036. http://dx.doi.org/10.1016/j.respol.2011.12.012.

Stagge, J.H., Davis, A.P., Jamil, E., Kim, H., 2012. Performance of grass swales for improving water quality from highway runoff. Wat. Res. 46, 6731-6742. http://dx.doi.org/10.1016/j.watres.2012.02.037.

Terzakis, S., Fountoulakis, M.S., Georgaki, D., Albantakis, D., Sabathianakis, I., Karathanasis, A.D., Kalogerakis, N., Manios, T., 2008. Constructed wetlands treating runoff in the central Mediterranean region. Chemosphere 72, 141-149. http://dx.doi.org/10.1016/j.chemosphere.2008.02.044.

Tukker, A., Butter, M., 2007. Governance of sustainable transitions: about the 4(0) ways to change the world. J. Clean. Prod. 15, 1, 94-103. http://dx.doi.org/10.1016/j.jclepro.2005.08.016.

van der Brugge, R., Rotmans, J., 2007. Towards transition management of European water resources. Water Resour. Manag. 21, 1, 249-267. http://dx.doi.org/10.1007/s11269-006-9052-0.

Willke, H., 2007. Smart Governance: Governing the global knowledge society. The University of Chicago Press. Chicago, USA.

Winz, I., Trowsdale, S., Brierley, G., 2014. Understanding barrier interactions to support the implementation of sustainable urban water management. Urban Water Journal, 11, 6, 497-505. http://dx.doi.org/10.1080/1573062X.2013.832777.

Woolthuis, R., Hooimeijer, F., Bossink, B., Mulder, G., Brouwer, J., 2013. Institutional entrepreneurship in sustainable urban development: Dutch successes as inspiration for transformation. J. Clean. Prod. 50, 91-100. http://dx.doi.org/10.1016/j.jclepro.2012.11.0.

Xu, M., Weissburg, M., Newell, J.P., Crittenden, J.C., 2012. Developing a Science of Infrastructure Ecology for Sustainable Urban Systems. Environ. Sci. Technol. 2012, 46, 7928-7929. http://dx.doi.org/10.1021/es33025534.

Zuo, X.J., Fu, D.F., Li, H., Singh, R.P., 2011. Distribution Characteristics of Pollutants and Their Mutual Influence in Highway Runoff, Clean-Soil Air Water 39, 10, 956-963. . http://dx.doi.org/10.1002/clen.201000422.

ANNEX 5: Análisis comparativo de las escorrentías producidas en un pavimento permeable y en una calzada convencional.

1. Introducción

Los pavimentos permeables continuos se enmarcan dentro de las tecnologías de gestión de las escorrentías urbanas conocidas como Sistemas de Drenaje Sostenible (SuDS). Muy extendidos en las zonas europeas de clima húmedo y continental, la experiencia y los casos desarrollados en el área mediterránea son, en comparación, todavía tímidos. Sin embargo, en los últimos años estas técnicas están recibiendo un impulso real en España (Casal-Campos, et al., 2012), notablemente en la costa norte (Gómez-Ullate et al., 2011), pero también en Madrid, Barcelona y la Comunidad Valenciana (Castro-Fresno et al., 2013). Se puede por tanto afirmar que la transición hacia este enfoque alternativo y complementario de la gestión de las escorrentías urbanas ha empezado en España; sin embargo, existe cierta reticencia a su empleo decidido por cuanto existe poca experiencia que demuestre el buen funcionamiento de estas soluciones, sobre todo bajo condiciones climáticas mediterráneas.

Los pavimentos permeables consisten en una capa de rodadura (asfáltica o de hormigón, generalmente), que permite la infiltración de la escorrentía hacia una capa de grava subyacente, donde se almacena temporalmente antes de que se infiltre al terreno natural (si el terreno y la calidad de la escorrentía así lo permiten) o se evacue fuera del sistema mediante drenes (Woods-Ballard et al., 2007, Puertas Agudo, et al., 2008). Esta técnica se emplea básicamente en zonas con baja intensidad de tráfico, como zonas de aparcamiento, calles residenciales, zonas de recreo o aceras. El pavimento permeable objeto de análisis constituye el aparcamiento para vehículos de la nueva piscina cubierta municipal de Benaguasil (Valencia). Su superficie total es de 785 m^2. La sección del pavimento contempla 25 cm de base de zahorra drenante compactada sobre la que descansa una capa de hormigón poroso de 12 cm de espesor con ligante Ecocreto (Figura 1).

Figura 1. *(a) Aparcamiento con pavimento permeable (Benaguasil, Valencia). (b) Detalle del hormigón poroso.*

El análisis mediante modelación matemática del funcionamiento hidráulico del mencionado pavimento poroso pone de manifiesto que, aún en climas mediterráneos, con características específicas como la torrencialidad, este tipo de soluciones proporcionan resultados favorables para la gestión de la escorrentía en el origen del sistema, contribuyendo con ello, además, a los beneficios en cuanto a la mejora que se consigue en la calidad de las aguas filtradas a su través (García-Haba et al., 2011).

Los objetivos que se persiguen en el presente trabajo se centran en analizar los rendimientos reales que, tanto desde el punto de vista de la cantidad como de la calidad del agua, se alcanzan con el uso de esta infraestructura en comparación con la respuesta de la calzada convencional adyacente. La monitorización implantada persigue cuantificar los excedentes de escorrentía drenados por el pavimento hacia la red y el caudal evacuado por un imbornal a la red en la calzada perimetral del aparcamiento. Cuando la capacidad de almacenamiento de la capa de gravas esté agotada, los excedentes llegarán a través del dren longitudinal a la arqueta que se encuentra al final de éste, en un extremo del aparcamiento. De la arqueta, los caudales excedentes son evacuados hacia la red de colectores que discurre por la calzada. Para comparar la diferencia con la escorrentía producida en condiciones habituales en una calzada impermeable, se monitoriza además un imbornal de la calzada perimetral al aparcamiento. Para ello se deriva la acometida del mismo hacia otra arqueta donde se instala la instrumentación antes de restituir los caudales al pozo de registro correspondiente.

2. Monitorización de la infraestructura

2.1 Monitorización de variables de cantidad

En la Figura 2 se representa un esquema del aparcamiento permeable con las dos arquetas que albergan la instrumentación para la campaña de monitorización; una de ellas recoge los excedentes drenados desde el pavimento permeable hacia la red y la otra permite monitorizar las escorrentías captadas por un imbornal en la calzada convencional.

En ambas arquetas se ha colocado un vertedero triangular en pared delgada para aforar el caudal que se vierte a la red de colectores. Asimismo, se ha instalado una sonda hidrostática de presión aguas arriba de los vertederos. Esta sonda registra la variación del nivel de agua y, además, permite conocer la columna de agua sobre el vértice de los vertederos. En el caso de la arqueta del pavimento permeable, es de esperar que los caudales recibidos sean mucho menores. Por ello, además de la medición del caudal con el vertedero, se ha instalado un caudalímetro de cubetas basculantes, mucho más preciso en el rango bajo de aforo. Si el caudal entrante a la arqueta supera la capacidad de medición del caudalímetro de cubetas, éste se medirá con la sonda de nivel y el vertedero triangular. En la arqueta del pavimento convencional se han instalado también ambos sistemas de medición, aunque en este caso se espera que el vertedero (de mayores dimensiones que el instalado en la arqueta del pavimento permeable) sea el principal medio de aforo de caudales.

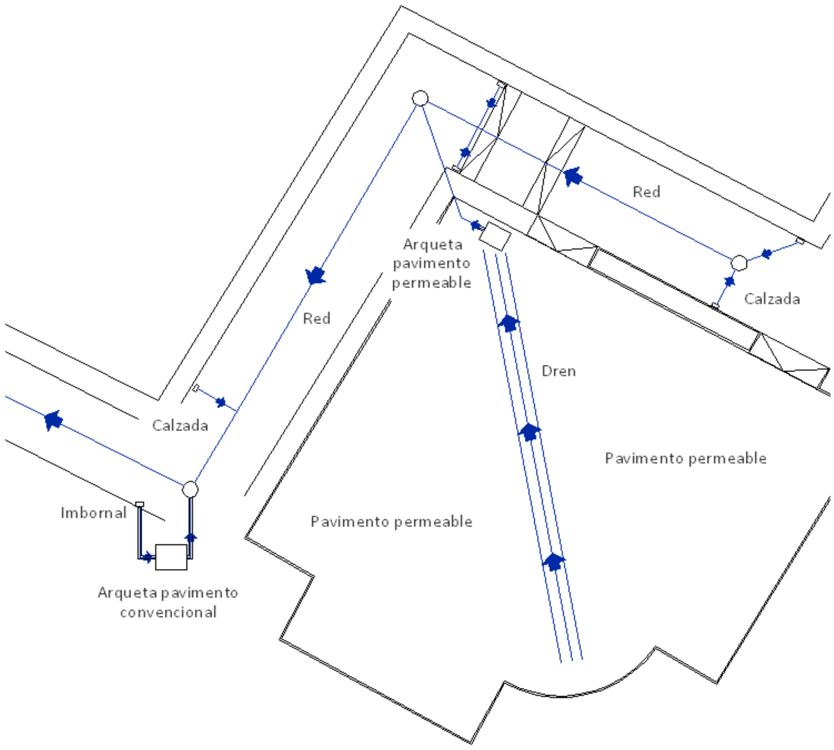


Figura 2. *Aparcamiento permeable: situación del dren longitudinal, arqueta de salida del pavimento permeable y arqueta conectada al imbornal de la calzada convencional.*

Las cuatro variables que se monitorizan son el número de pulsos acumulados por cada caudalímetro de balancín, con un intervalo de dos minutos, y el registro de nivel de cada una de las sondas de presión, con intervalo de un minuto. Del registro de estos datos, las variables de interés derivadas son el caudal de escorrentía generado por el pavimento permeable y el generado por el área drenante al imbornal del pavimento convencional.

2.2 Monitorización de variables de calidad

La calidad del agua ha sido analizada igualmente en ambos puntos: agua drenada por el pavimento permeable (punto de medición con código B41) y agua captada por el imbornal del viario convencional adyacente (punto de medición con código B42). Para ello, en las arquetas donde se capta el agua procedente de ambos puntos, se han colocado recipientes con un embudo dotado de una malla metálica para evitar la entrada de material grueso no deseado, cuya finalidad es captar el agua vertida en las primeras oscilaciones del balancín. El procedimiento seguido en la recogida y procesamiento de muestras consta de los siguientes pasos: (1) se produce un evento de lluvia suficientemente significativo, (2) en el menor tiempo posible, se recogen las muestras tomadas en el evento, (3) se realiza medición de parámetros físico-químicos generales (conductividad, oxígeno disuelto (OD), pH y temperatura) in situ, (4) se reponen las unidades de muestreo con material limpio, (5) se trasladan las muestras, conservadas en neveras, al laboratorio y se procede en un plazo máximo de 24 horas al análisis de los siguientes parámetros: DBO_5 (Respirometría mediante sistema de control OxiTop®), Sólidos Suspendidos Totales (UNE-EN 872), turbidez (turbidímetro TN100 Eutech), Nitrógeno Total (test Spectroquant®: ISO 11905-1 + Fotometría), Fósforo Total (test Spectroquant®: disgregación + ISO 6878/1).

3. Resultados y discusión

3.1 Cantidad

El periodo analizado comprende desde el 29/09/2012 hasta el 15/05/2013. De un total de 14 eventos registrados en el período, el pavimento permeable ha drenado agua en 7, mientras que el imbornal ha recogido escorrentía en 12, lo que demuestra el control en origen que se consigue con este tipo de soluciones. Además, el análisis detallado de los hidrogramas registrados a la salida del dren y su comparación con los registrados en el imbornal, pone de manifiesto la capacidad de laminación que también se consigue con la infraestructura. Los tiempos de respuesta del pavimento permeable frente a los observados en la calzada convencional llegan a estar retrasados un promedio de 4 horas.

Con las áreas drenantes a cada arqueta, se calcula el rendimiento volumétrico de cada sistema de drenaje. Un rendimiento del 100% significaría que la estructura ha sido capaz de almacenar todo el volumen de lluvia precipitado, sin verter nada a la red de colectores. El pavimento permeable, en los eventos en los que drena, presenta rendimientos volumétricos siempre superiores al 97%, lo que significa que es capaz de retener prácticamente toda el agua que precipita sobre el mismo sin apenas producir vertidos a la red de colectores. En la Tabla 1 figuran los rendimientos volumétricos del pavimento permeable durante el período analizado. Puede observarse como en eventos de poco volumen y poca intensidad (eventos 4, 5, 7), el control de escorrentías es total. En eventos de poco volumen pero con picos de intensidad máxima importante (eventos 6, 9, 13), se produce rebose a la red, pero los rendimientos siguen siendo muy altos. Estos resultados respaldan los obtenidos previamente mediante modelación matemática (García-Haba, et al., 2011).

Nº EVENTO	VOLUMEN LLUVIA (mm)	INTENSIDAD MÁXIMA 2-min (mm/h)	VOLUMEN DRENADO (mm)	RENDIMIENTO VOLUMÉTRICO (%)
1	72	-	-	-
2	7.4	-	-	-
3	55.20	90.00	1.01	98%
4	5.40	6.00	0.00	100%
5	4.00	6.00	0.00	100%
6	6.00	30.00	0.48	92%
7	4.20	6.00	0.00	100%
8	4.40	18.00	0.00	100%
9	10.60	30.00	0.28	97%
10	1.80	18.00	0.00	100%
11	13.00	6.00	0.52	96%
12	30.20	6.00	0.64	98%
13	11.00	12.00	0.18	98%
14	78.20	60.00	1.20	98%

Tabla 1. *Rendimientos volumétricos del pavimento permeable.*

3.2 Calidad

La calidad del agua en el pavimento permeable y en el imbornal de la calzada convencional, ha sido analizada en 7 y 10 eventos respectivamente durante el período estudiado. La diferencia entre ambos se debe a que en tres de los eventos monitorizados el pavimento permeable había captado el 100% del agua de lluvia, no drenando agua hacia la arqueta de recogida de muestra. Los resultados obtenidos durante los meses monitorizados se muestran en la Fig. 3. En dicha figura se puede observar que la calidad del agua drenada por el pavimento permeable (B41) ha ido mejorando a lo largo del tiempo para todas las variables de calidad analizadas desde el inicio hasta el evento ocurrido en abril de 2013. En términos generales, los valores obtenidos serían comparables a los de un agua residual urbana (ARU) con bajas concentraciones. Los valores de DQO en ambos puntos apenas superan en un caso los valores umbrales de 125 mgL^{-1} establecidos por la normativa sobre tratamientos de aguas (RD 509/1996) a la salida de una estación depuradora de aguas residuales urbanas (EDAR). También los valores de nitrógeno total (NT) y fósforo total (PT) se situarían dentro de esta categoría. Únicamente los sólidos suspendidos totales (SST) están en numerosas ocasiones por encima de la normativa indicada.

El verano de 2012 fue muy seco. Esto favoreció la acumulación de contaminantes en la superficie, que combinados con la magnitud e intensidad del primer evento analizado, propiciaron un lavado y arrastre considerable, aunque días antes ya se había producido un episodio de poca magnitud. Además, en el verano de 2012 se realizaron pequeñas obras de terminación de la infraestructura, entre ellas la adecuación de la arqueta para la monitorización, que también pudieron haber influido en las altas concentraciones de sólidos registradas en el primer evento de la serie, de hasta

295 mg·L^{-1}. A partir de entonces, el patrón de lluvias ha sido más continuo y las concentraciones obtenidas han sido siempre menores, a pesar de que no se han realizado labores de limpieza de superficies, lo que no parece haber perjudicado el funcionamiento del sistema posiblemente debido a que hasta abril de 2013 el tráfico de vehículos en esta zona ha sido prácticamente nulo.

Sin embargo, a partir de abril de 2013 se puede apreciar un ligero aumento de las concentraciones de todas las variables analizadas, por ejemplo de 5 a 29 mg·L^{-1} para los SS, que podría estar relacionado con la reanudación de las obras en el edificio de la piscina, lo que provocaría un aumento de la producción de polvo y la consecuente deposición sobre las superficies colindantes, además del aumento del tráfico y estacionamiento de vehículos en el aparcamiento de pavimento permeable. A partir de este momento, aunque no se ha producido un aumento importante en las concentraciones medidas en el agua drenada por el pavimento permeable, sería conveniente programar labores de limpieza, ya que un correcto mantenimiento es crucial para mantener una infiltración óptima por el pavimento (Scholz y Grabowiecki, 2007; Bean et al., 2007). Esta infiltración podría verse perjudicada por el aumento de contaminantes que tendrá lugar a partir de la apertura de la piscina al público y el consiguiente aumento de tráfico, ya que éste incrementa notablemente la concentración de contaminantes en la escorrentía.

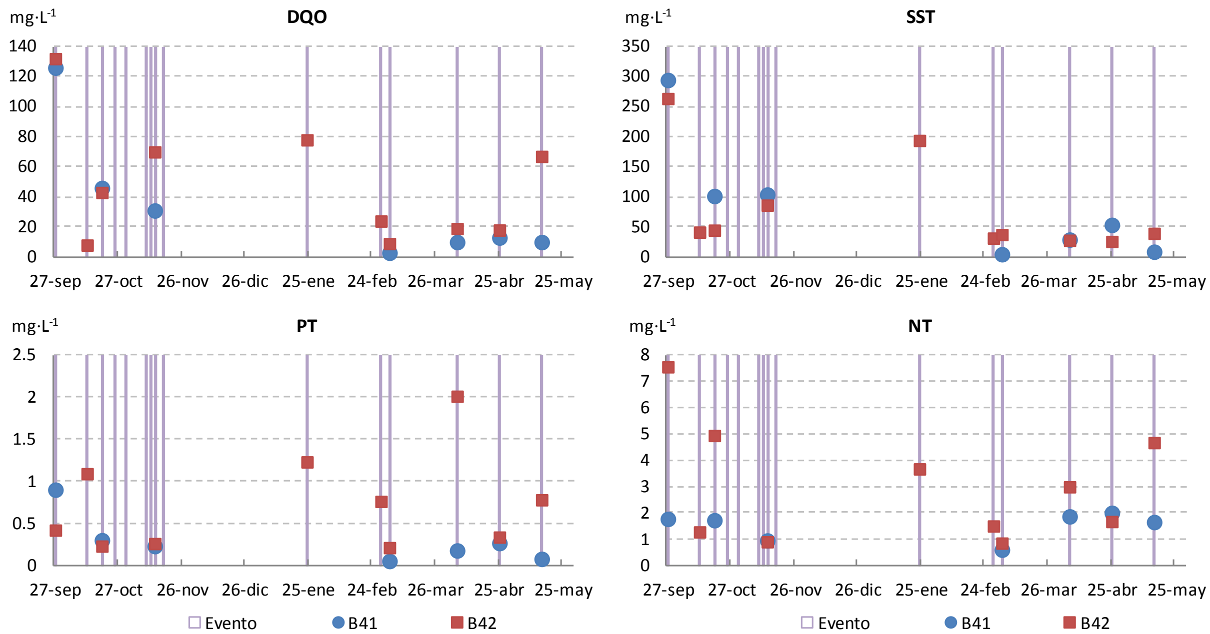


Figura 3. *Resultados de las variables de calidad (DQO, SST, PT y NT) en los puntos de control B41 (Pavimento permeable) y B42 (imbornal) entre sep-2012 y may-2013. Las barras indican los eventos registrados.*

Comparando los resultados anteriores con los correspondientes al agua captada por el imbornal en la calzada convencional (B42), se aprecia que la calidad de la primera es generalmente mejor que la segunda. Se puede afirmar que el pavimento permeable, tras los primeros lavados, actúa efectivamente como filtro, reteniendo las partículas depositadas en su superficie. La retención de contaminantes por los pavimentos permeables también ha sido contemplada en otros estudios (Brattebo y Booth, 2003).

La calidad del agua captada por el imbornal (B42) no presenta tendencias tan evidentes como la del punto B41, pero sí que se puede percibir que, por lo general, la concentración de las variables estudiadas es mayor cuando el periodo seco transcurrido entre eventos es prolongado. Por ejemplo, tras el mayor periodo seco transcurrido entre mediados de noviembre de 2012 y finales de enero de 2013, se produjo un aumento considerable de las concentraciones de SST (de 86 a 194 $mg{\cdot}L^{-1}$), NT (de 0.9 a 3.7 $mg{\cdot}L^{-1}$), PT (0.26 a 1.23 $mg{\cdot}L^{-1}$).

En relación con el resto de parámetros analizados, no mostrados en la Figura 3, se puede comentar que la DBO_5 es en general baja, con máximos de 12.7 y 30.5 mg·L-1 en los puntos B41 y B42 respectivamente. En ambos casos se trata de materia orgánica poco biodegradable, ya que esos valores representan porcentajes del 10 y 39% de la DQO respectiva (a este respecto cabría recordar que esta relación se sitúa en el entorno del 65% en ARU). La turbidez presentó una correlación lineal positiva con los SST, obteniéndose una relación Turbidez/SST de 1.5 (R^2 = 0.96) y 0.9 (R^2 = 0.70) para los puntos B41 y B42 respectivamente, lo que indica que los sólidos presentes en el agua drenada por el pavimento permeable conferían una mayor turbidez al agua. El agua presentó buenos niveles de oxígeno disuelto, acordes con las bajas DBO_5, con valores medios de 88 y 85% respecto al OD de saturación. La conductividad fue notablemente baja, esperable al tratarse de agua de lluvia, pero bastante variable: algo más en el agua drenada por el pavimento permeable, entre 93 y 406 $\mu S{\cdot}cm^{-1}$, que en el pavimento convencional (113-365 $\mu S{\cdot}cm^{-1}$). Por último, con relación al pH, destacan los valores medidos en los primeros eventos en el agua drenada por el pavimento permeable, que alcanzaron valores superiores a 9. Este alto valor podría estar relacionado con el lavado de materiales de obra que pudieran conferir alcalinidad al agua. En el resto de los puntos muestreados los valores estuvieron entre 7.5-8.

4. Conclusión

La campaña de monitorización del pavimento permeable en Benaguasil demuestra la eficacia en el control de escorrentías que se consigue con este tipo de soluciones, aún en climas mediterráneos marcados por una alta torrencialidad. En cuanto a la calidad de las escorrentías, las primeras aguas pluviales que son drenadas por ambas superficies presentan concentraciones bajas de contaminantes. Sin embargo, la carga contaminante no es despreciable y si su destino final fuera un cauce natural deberían considerarse opciones para su tratamiento. Se ha observado que tras un primer lavado de los materiales residuales de las obras de terminación, el agua drenada por el pavimento permeable ha ido mejorando su calidad a lo largo del período de estudio. Además, en general, la calidad de dicha agua ha sido mejor que la recogida por el imbornal de la calle con pavimento convencional, por lo que el pavimento permeable está actuando como filtro de las partículas depositadas en superficie, suponiendo ello un beneficio adicional al efecto de laminación sobre la escorrentía que ejerce esta infraestructura. Será importante estudiar la evolución a largo plazo de este efecto de filtrado, por si ello pudiera afectar a su funcionamiento hidráulico.

Los resultados presentados en este artículo forman parte de la investigación desarrollada en el proyecto Life+ "AQUAVAL Sustainable Urban Water Management Plans, promoting SUDS and considering climate change, in the province of Valencia" (Life08ENV/E/000099), apoyado por fondos FEDER de la Unión Europea y por la Diputación de Valencia.

Referencias

Bean, E.Z.; Hunt, W.F., Bidelpach, D.A. (2007) Field survey of permeable pavement surface infiltration rates. J. Irrig. Drain. Eng. ASCE, 133:249-255.

Brattebo, B.O.; Booth D.B. (2003) Long-term stormwater quantity and quality performance of permeable pavement systems. Wat. Res. 37:4369-4376.

Casal-Campos, A., Jefferies, C. and Perales-Momparler, S. Selecting SUDS in the Valencian Region of Spain, Wat. Pract. & Tech. 2012, 7 (1). doi:10.2166/wpt.2012.001.

Castro-Fresno, D., Andrés-Valeri, V. C., Sañudo-Fontaneda, L. A., Rodriguez-Hernandez, J. Sustainable Drainage Practices in Spain, Specially Focused on Pervious Pavements. Water 5, 2013 (1), 67-93. http://www.mdpi.com/2073-4441/5/1/67.

García-Haba, E.; Perales-Momparler, S.; Andrés-Doménech I. (2011). Control de escorrentías urbanas mediante pavimentos permeables: aplicación en climas mediterráneos. II Jornadas de Ingeniería del Agua. Modelos numéricos en dinámica fluvial. ISBN-13: 978-84-615-4023-5. Barcelona, 5-6 octubre 2011.

Gomez-Ullate, E., Castillo-Lopez E., Castro-Fresno, D. and Bayon, J. R. Analysis and Contrast of Different Pervious Pavements for Management of Storm-Water in a Parking Area in Northern Spain, Water Resources Management. 2011, 25 (6), 1525-1535.

Puertas Agudo, J.; Suárez López, J.; Anta Álvarez, J. Gestión de las aguas pluviales. Implicaciones en el diseño de los sistemas de saneamiento y drenaje urbano. CEDEX. Gobierno de España (2008).

Scholz, M., Grabowiecki, P. (2007) Review of permeable pavement systems. Build. Environ. 42:3830-3836.

Woods-Ballard B.; Kellagher R.; Martin P.; Jefferies C.; Bray R.; Shaffer P. The SUDS Manual. CIRIA C697. London 2007.

ANNEX 6: Inner-city SUDS retrofitted sites to promote sustainable stormwater management in the Mediterranean region of Valencia: AQUAVAL (Life+ EU programme).

Abstract

Stormwater management demonstration sites using Sustainable Drainage Systems (SUDS) as a complement to the existing water infrastructure have been retrofitted in two cities in the Valencian Region of Spain, as part of the AQUAVAL project (EU LIFE+2008 Community Initiative). The sites in the cities of Xàtiva and Benaguasil provide showcases for Southern European Regions in the development of a sustainable drainage culture, where only superficial imprint of these alternative solutions to traditional sewer systems can be found.

In addition to an overview of the retrofitted demonstration sites, these article presents the AQUAVAL project objectives and activities, and highlights the importance of involving public administrations in the diffusion of SUDS technologies and approach (acting as beneficiaries as well as co-financers in this project) in order to boost a more sustainable management of rainwater in municipalities, ensuring that rainwater is included in water resources and land use planning policies.

Keywords

Inner-city, Mediterranean regions, retrofit, stormwater management, sustainable drainage

1. Introduction

The Committee of the Regions of the European Union (2011) indicates that water policy must be based on three elements – storage, containment and drainage – that aim to reduce peaks in the water cycle, which enables surplus water to be discharged naturally, while ensuring that enough remains available for times when water is scarce.

Development often alters natural drainage by replacing free draining ground with impermeable surfaces, gulleys, pipes, sewers and channel. Also, it can remove vegetation and compact the ground. These changes increase the total volume and flow of runoff and may make areas more susceptible to flooding locally but also exacerbate river flooding. We need to have drainage systems that can adapt to and manage the extreme events including flooding and periods of drought, while reducing our carbon emissions (Dickie, S. *et al*, 2010).

Surface water drainage systems developed in line with the ideals of sustainable development are collectively referred to Sustainable Drainage Systems (SUDS). SUDS objectives are to minimise the impacts from the development on the quantity and quality of the runoff, and maximise amenity and biodiversity opportunities (Woods-Ballard, B. *et al.*, 2007). Types of SUDS include green roofs, bio-retention zones, detention basins, filter drains, filter strips, flow control systems, infiltration trenches and basins, permeable paving, retention ponds, soakaways, swales and wetlands.

Additional benefits, not only for new developments but also for retrofitting, of these alternative solutions to traditional sewer systems to manage urban stormwater management (e.g. reduce energy and potable water use, air quality improvements, increased property value, urban heat island mitigation, etc.), have been widely reported (Digman, C. *et al.*, 2012). However, only superficial imprint of SUDS can be found in Spain (Deutsch, J.C. *et al.*, 2003; Perales, S. and Andrés-Doménech, I., 2008; Febles *et al.*, 2009).

AQUAVAL ("The efficient management of rain water in urban environments") is a programme funded by the EU LIFE+ Community Initiative that aims to boost a more sustainable management of rainwater in municipalities ensuring that rainwater is included in water resources and land use planning policies. It is a showcase not only for the Valencian Region, but also for the rest of Spain and the Mediterranean, as demonstrate the fact that has been selected as an example of good practice at European level (Progress Consulting S.r.l. and Living Prospects Ltd., 2011), being relevant to give inputs and recommendations to policy opinion reports at European level.

The strength of the AQUAVAL project to influence the required change of paradigm (promoting stormwater management as a key component of the sustainable city), lays on the representativeness of its partnership, integrated by local and regional authorities, SMEs and universities (Ayuntamiento de Xàtiva, Ayuntamiento de Benaguasil, Fundación Comunidad Valenciana-Región Europea de la Generalitat Valenciana, PMEnginyeria -in Spain- and University of Abertay-Dundee - in Scotland), and the active support of its co-financers (Diputación de Valencia and the European Union).

2. AQUAVAL project objectives and activities

AQUAVAL main target is to find, implement and promote innovative solutions to decrease the impacts of developments on quantity and quality of urban run-off (e.g. flooding, combined sewer overflow –CSO- spills, pollution, drought, etc.). The municipal scale has been chosen for the project implementation, with case studies in two different municipalities within de province of Valencia: Xàtiva and Benaguasil.

The guiding principle is to make the best use of municipalities' landscape and morphology in order to integrate water infrastructure using Sustainable Drainage Systems (SUDS), adding social and environmental values.

To achieve it, and with an overall budget of 1.228.618 €, the project is promoting a wide application of scientifically verified technologies and approaches within the European region, extending the use of SUDS to regions where they are not current practice, such as Spain, and in particular to the Province of Valencia, with the collaboration of SUDS experts from the University of Abertay (Scotland).

AQUAVAL specific objectives include:

- Preventing sewage overflow in order to improve the quality of water of the Albaida and Turia rivers that receive urban run-off;
- Preventing flooding and frequent overflows from the town centre's sewage network under heavy rain;
- Making the drainage infrastructure versatile enough to cope with the effect of climate change;
- Reducing electricity consumption (and therefore, CO_2 emissions to the atmosphere) in urban water management (pumping, sewer treatment plants, etc.) and in buildings (i.e. with the use of green roofs);
- Reducing the "heat island" effect in towns and cities;
- Saving drinking water by using rainwater for irrigation, street cleaning, etc.;
- Promoting the implementation of SUDS in southern Europe;
- Developing municipal policies that integrate environmental aspects into legislation related to land use planning and water management;
- Creating new employment niches;

- Achieving industrial diversification while introducing new materials and products and drainage systems.

Particularities of the Mediterranean region, such as dry weather combined with high intensity storms and prevalence of dense and highly impermeable cities with combined sewer systems, mark differences with other European regions where the use of SUDS are more common. These factors, together with others (e.g. the fact that infrastructures investments are highly politically influenced) have been considered all through the length of the project.

The AQUAVAL project, that started in January 2010 and is due to conclude in September 2013, in order to promote stormwater management as a key component of the sustainable city, comprises the following main groups of activities (in addition to the management activities inherent to a Life+ European project):

- Analysis of current situation and proposal for SUDS demonstration sites;
- Design, construction and monitoring of demonstration sites;
- Production of Sustainable Urban Stormwater Management Plans and new Water and Land Use Planning Policies;
- Creation and coordination of a Working Group in Water Efficiency;
- Dissemination and promotion of the use of SUDS.

Specific tasks undertaken and results obtained are explained on the following sub-chapters.

2.1. Analysis of current situation and proposal for SUDS Demonstration Sites

First stage of the project was to assess the current combined sewer networks hydraulic performance. Although critical locations are well known (frequent overflows form the town centre's sewage occur in both Xàtiva and Benaguasil), the municipalities had little data on the sewer system, and the networks were partially surveyed to take covert/invert levels and pipe diameters. With that information, an assessment of the current sewer networks hydraulic situation was undertaken with the use of the XPSWMM software (XPSoftware), growing in detail around the most suitable areas to allocate the demonstration SUDS. The analysis confirmed that the current combined sewer networks are insufficient to appropriately manage the runoff, and flooding occurs in several parts of the networks. Additionally, different climate change scenarios have been introduced in the analysis. This model forms the base to predict the benefits of different SUDS techniques implementation in the future.

Location and type of the SUDS demonstration infrastructures was decided in September 2010. Six sites in a range of common urban spaces and land uses were selected and appropriate SUDS techniques proposed by means of a decision-support process. This primarily consisted of the systematic application of key selection criteria through matrices and scores, followed by a brief sustainability analysis. Apart from the main criteria to reduce current drainage problems, stakeholders' preferences and opinions as well as educational and social opportunities were highly considered throughout the process (Casals-Campos, A. *et al.*, 2012).

2.2. Design, Construction and Monitoring of Demonstration Sites

In the frame of this project, water management demonstration sites have been implemented using SUDS as a complement to the existing water infrastructure in both Xàtiva and Benaguasil. A summary of the SUDS constructed in each one of the sites (six in total) is contained in section 3. All sites have been equipped with suitable instrumentation in order to monitor these infra-structures, both in terms of quantity and quality of the runoff.

An important aspect to highlight is that the design and construction activities took longer than initially scheduled. This was partly due to the lack of experience on this type of projects of con-sultants and construction companies, which required more assistance and a closer and more frequent supervision from the AQUAVAL technical partners (PMEnginyeria and University of Abertay-Dundee, experts on SUDS) than initially expected.

Overall construction ended in August 2012 and monitoring activities started in October 2012. A full Hydrological year will be monitored (until September 2013), and these 12 months of data will be used to support the Sustainable Urban Management Plans and Water and Land Use Planning Policies for Xàtiva and Benaguasil.

In addition to the six sites which SUDS construction was funded by the AQUAVAL project, Ayun-tamiento de Benaguasil obtained national funding to urbanize the municipal covered swimming pool. Taking advantage of the knowledge gained during the beginning of the AQUAVAL project, the City Council decided to build a permeable pavement parking (SUDS infrastructure) instead of the conventional option of an impermeable one. Its construction was completed before the end of 2010. The "open ceremony" of this parking was on 21st June 2011.

Openning of the public indoor swimmingpool permeable car park. Benaguasil (Valencia), June 2011.

2.3. Production of Sustainable Urban Stormwater Management Plans and new Water and Land Use Planning Policies

Activities related the production of Sustainable Urban Stormwater Management Plans and new Water and Land Use Planning Policies are currently being undertaken, including an initial “State of the Art” study on how other cities worldwide have implemented SUDS in their water management plans.

Experiences in cities as Chicago and Philadelphia in the USA, Melbourne in Australia and Glasgow in the UK will contribute to a smoother transition towards the implementation of SUDS in the Valencian Region.

2.4. Creation and coordination of a Working Group in Water Efficiency

In the frame of this initiative, a Working Group on Water Management Efficiency has been created, allowing the participation of the main actors of the water sector in the Valencian Region, public as well as private. It enables the identification of new opportunities and work niches, by means of the development of new materials and products that allow the reuse of rain water and the development of sustainable drainage systems.

The Working Group in Water Efficiency, which holds regular meetings since the start of the project, has shown very useful to shear experiences with other public and private entities, and the interest on implementing similar actions in other municipalities is growing. As an example, *Federación Valenciana de Municipios y Provincias* (FVMP), a member of the working group that represents more than 500 municipalities in the Valencian Region, has express their interest in expand the AQUAVAL model to those municipalities, which have similar problems to the pilot cities (Xàtiva and Benaguasil) and share the objective of the project.

Working Group in Water Efficiency meeting. Valencia, November 2010.

2.5. Dissemination and promotion of the use of SUDS

The AQUAVAL project has been presented at many regional, national and international events, and all type of stakeholders have expressed their interest on following its progress. Several public authorities, architects and engineers have already visited the SUDS demonstration sites, and many others (at national and international level) are willing to do so. In that respect, AQUAVAL partners are preparing a Site Visit event in May 2013 that will be opened to all interested (national and international).

Educational sites have been installed in each one of the sites (as shown in the picture of Xàtiva's site 2 below), and the project website (www.aquavalproject.eu) is permanently updated with news, events, newsletters, etc. The AQUAVAL project could boost the creation of new urban planning models and local legislation that will generate new business opportunities and new products and services that will generate new areas of employment.

20 | SÁBADO, 23 DE JUNIO DE 2012 Levante EL MERCANTIL VALENCIANO

La Costera-La Canal-La Vall d'Albaida

Un huerto en el techo del colegio

▶ La cubierta del Gozalbes Vera de Xàtiva alberga una experiencia piloto sobre el aprovechamiento del agua pluvial para fines ecológicos y de ahorro

SERGIO GÓMEZ XÀTIVA

■ Su acceso es complicado y su evolución, difícil de comprobar en las entrañas de la urbe. Pero la azotea del Gozalbes Vera, el colegio público de Xàtiva, se ha convertido, desde hace meses, en el escenario de un proyecto piloto que explora nuevas formas de sostenibilidad medioambiental. El programa Aquaval –financiado por la UE, el ayuntamiento y la diputación– ha convertido la cubierta del centro en un laboratorio donde se ensayan las potencialidades del drenaje ecológico. Un huerto que da cabida a diversas variedades vegetales, regado con el agua drenada de lluvia, es la visión más impactante en la parte alta del colegio, pero detrás de la actuación hay mucho más.

La cubierta ejerce ahora como una capa permeable que se comporta igual que un sumidero. Emulando el ciclo natural del agua, ésta es filtrada a través de unos tubos y gestionada de manera superficial para su reciclado, posterior infiltración al huerto y vertida más tarde directamente a un cauce natural completamente depurada, libre de contaminación. Según explica Gonzálo Valls, director de la obra, el proyecto permite retener el agua en una serie de puntos localizados «para que no llegue toda de golpe a los puntos de vertido», con tal de «evitar las fugas y mejorar la depuración del agua en origen», indica. A la larga, el drenaje sostenible posibilita la descongestión del alcantarillado en caso de lluvia.

Los recursos hídricos obtenidos son aprovechados para la limpieza del centro docente y el riego de las plantas. Además, el sistema de cultivo hará que la temperatura bajo la cubierta descienda hasta en 5 grados en el colegio, consiguiendo «un ahorro energético importante», tal como destacó el alcalde de Xàtiva, Alfonso Rus, en su visita al huerto, ayer. El modelo permitirá reducir el consumo de agua potable y electricidad en el colegio. El edil de Juventud, Enrique Perigüell, resaltó que los resultados obtenidos serán seguidos de cerca durante un año, de modo que el sistema podría ser aplicado a otros edificios.

Inversión comunitaria

El proyecto se enmarca dentro de un plan global promovido con los fondos comunitarios Life+ que destina 1,2 millones a la ejecución de actuaciones sostenibles. Rus indicó que el modelo «se aplica con éxito en otros países» y que Xàtiva «ha tomado la delantera».

El alcalde, Alfonso Rus, colocando una de las semillas del proyecto, ayer en el Gozalbes Vera. PERALES IBORRA

El huerto se ubica en lo alto del centro docente. PERALES IBORRA

Newspaper article about Xàtiva's green roof (Levante, 23rd June 2012).

AQUAVAL partnership structure allows the interaction between different departments at city level, and within cities, and establishes a transnational learning arena with professionals with different expertise and backgrounds. It is worth highlighting the direct involvement of politicians in all activities through the project.

Regional and local politicians during a site visit. Benaguasil, February 2010 (Valencia).

3. Inner-city suds retrofitted sites

Stormwater management demonstration sites using SUDS as a complement to the existing water infrastructure have been built in two cities in the Valencian Region of Spain. The sites in the cities of Xàtiva and Benaguasil provide showcases for Southern European Regions in the development of a sustainable drainage culture.

In the frame of the project, monitoring and sampling activities of inflows and outflows in SUDS demonstration infrastructures are currently taking place, in order to analyse and quantify the improvement derived from the use these innovative techniques to demonstrate, in a pioneering way, the validity of the use of SUDS in semi-arid climates as the Mediterranean.

A summary of the SUDS constructed in each one of the sites (six in total) is presented herein.

3.1. Demonstration sites in Xàtiva (Valencia).

3.1.1. Xàtiva SITE 1: Sports City.

The main objective of this pilot is to decrease the runoff volume that discharges into the combined sewer, at the same time that it provides some treatment to that runoff. The action designed in this area consists of the construction of a vegetated swale along the Villa B street, together with a retention-infiltration basin at the corner of the Sports City. Part of the runoff volume will be removed through evaporation, plant transpiration and infiltration. Excess runoff from extreme events is spilled to the sewer system.

Retention-infiltration basin in Xàtiva (Valencia).

3.1.2. Xàtiva Site 2: North Ring Road

A large vegetated swale with a width of 5 m has been built to manage run-off from adjacent roads, both the public one (North Ring Road) and the private section within the Pereres housing development. The swale has been complemented with four pedestrian crossings and two emergency spillways.

Vegetated swale in Xàtiva (Valencia).

Green roof in Xàtiva (Valencia).

3.1.3. Xàtiva Site 3: Gozalbes Vera Public School

The public school Gozalbes Vera is located in the very inner city, next to the main avenue in the city and a park.

This school has been retrofitted with a 475 m^2 green roof, a 3.000 liter tank (for the use of rainwater for watering the plants in the patio etc. and cleaning tasks) and a re-paving of the playground with porous concrete.

3.2. Demonstration sites in Benaguasil (Valencia).

3.2.1. Benaguasil Site 1: Costa Ermita Park

In this park, located in the road from Benaguasil to the hermitage of Nuestra Señora de Montiel, a serial of detention-infiltration basins have been built to control run-off coming from the side of the mountain and the Costa L'Ermita street.

The main objective of this infrastructure is to reduce the quantity of runoff and sediments that reaches the main avenue in town, further down the hill, as the municipal sewer combined system is not able to cope, and water flows superficially down the streets causing flooding damage in garages and houses in the lower part of the municipality.

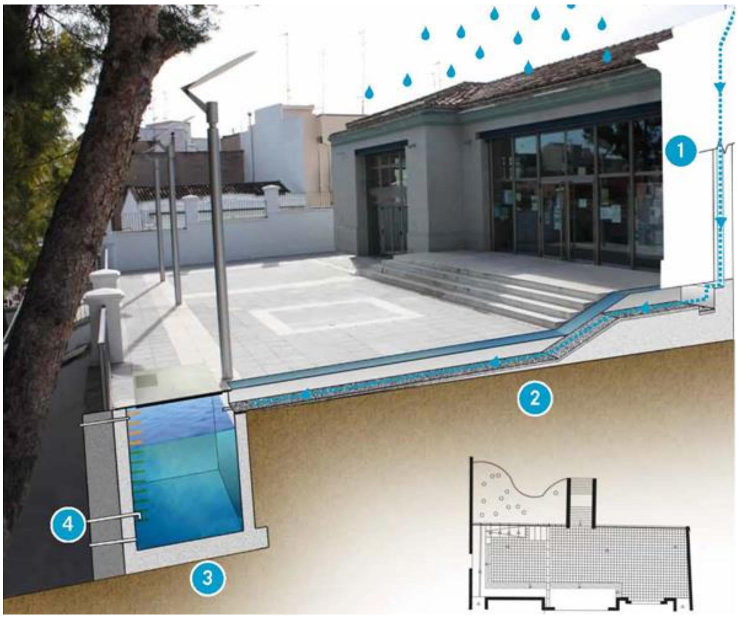
Series of detention-infiltration basins in Benaguasil (Valencia).

3.2.2. Benaguasil Site 2: Youth Center

In the main access to the Youth Center building, located in the Avenida de Montiel, a 20 m^3

rainwater harvesting tank has been rebuilt on site to collect run-off from part of the building roof. Stored water will be used for gravity irrigation of the public gardens and cleaning of the square located further down.

Building works have included the execution of a channel from the downspouts of the roofs to the cistern, covered by a porous crystal for educational purposes.



Schematic representation of the rainwater harvesting tank in Benaguasil (Valencia).

Run-off disconnected to a nearby retrofitted detention-infiltration basin in Benaguasil (Valencia).

3.2.3. Benaguasil Site 3: Les Eres Industrial Area

In this area, the roof and the paved courtyard run-off coming from a warehouse in the industrial park has been disconnected from the combined sewer system and redirected to a detention basin rebuilt in a former conventional public green area.

4. Conclusions

SUDS are innovative solutions for stormwater management in Mediterranean regions, where these systems are still highly unknown. With the objective of extending its use to regions where they are not current practice, such as Spain, six excellent demonstration sites have been retrofitted in inner-city sites of the municipalities of Xàtiva and Benaguasil (Valencia) in the frame of the AQUAVAL (EU LIFE+2008 Community Initiative). These alternative solutions to traditional sewer systems are being monitored (both water quality and quantity wise) for a year until the end of the project (September 2013), and it is expected that they provide proof of concept in the field.

Projects like AQUAVAL that, in addition to technical aspects, integrates capacity building measures, with the collaboration of administrative bodies, private companies, universities and non-profit organizations are of paramount importance to extend the use of SUDS in Mediterranean regions.

Acknowledgments

Aquaval project partners would like to thank the co-financing received from the European Programme Life+ and from Diputación de Valencia (Spain).

List of references

Casal-Campos, A., Jefferies, C. and Perales-Momparler, S. (2012). Selecting SUDS in the Valencian Region of Spain. Wat. Pract. & Tech., Vol 7 no1.

Committee of The Regions of the European Union (2011). The role of regional and local authorities in promoting sustainable water management. Doc. CDR5-2011-FIN-AC_EN, approved in the 91st plenary *session of the 30th June and 1st July 2011 in Brussels.*

Deutsch, J.C., Revitt, M., Ellis, B. and Scholes, L. (2003). Review of the Use of Stormwater BMPs in Europe. DAYWATER, Report 5.1.

Dickie, S., McKay, G., Ions, L. and Shaffer, P. (2010). Planninfg for SuDs – making it happen. CIRIA C687. London.

Digman, C., Ashley, R., Balmforth, D., Balmforth, D., Stovin, V. and Glerum, J. (2012). Retrofitting to manage surface water. CIRIA C713. London.

Febles D., Perales S. y Soto R. (2009). Innovación y Sostenibilidad en la Gestión del Drenaje Urbano: Primeras Experiencias de SuDS en la Ciudad de Barcelona. Jornadas de Ingeniería del Agua. CEDEX. Madrid. 27-28 Octubre 2009.

Perales S. and Andrés-Doménech I. (2008). Los sistemas urbanos de drenaje sostenible: una alternativa a la gestión del agua de lluvia. Revista Técnica de Medio Ambiente, C&M Publicaciones, 124 (Enero – Febrero 2008), p. 92–104.

Progress Consulting S.r.l. and Living Prospects Ltd. (2011). The role of regional and local authorities in promoting a sustainable water policy. Final Survey Report. Doc cdr-180. European Union. (Accesses 10th Nov 2012: http://portal.cor.europa.eu/europe2020/news/Documents/Water/Water%20Survey%20Full%20Report%20Final.pdf).

Woods-Ballard B.; Kellagher R.; Martin P.; Jefferies C.; Bray R.; Shaffer P. (2007). The SUDS Manual. CIRIA C697. London.