# Review on flexible UWCS and transitional pathways

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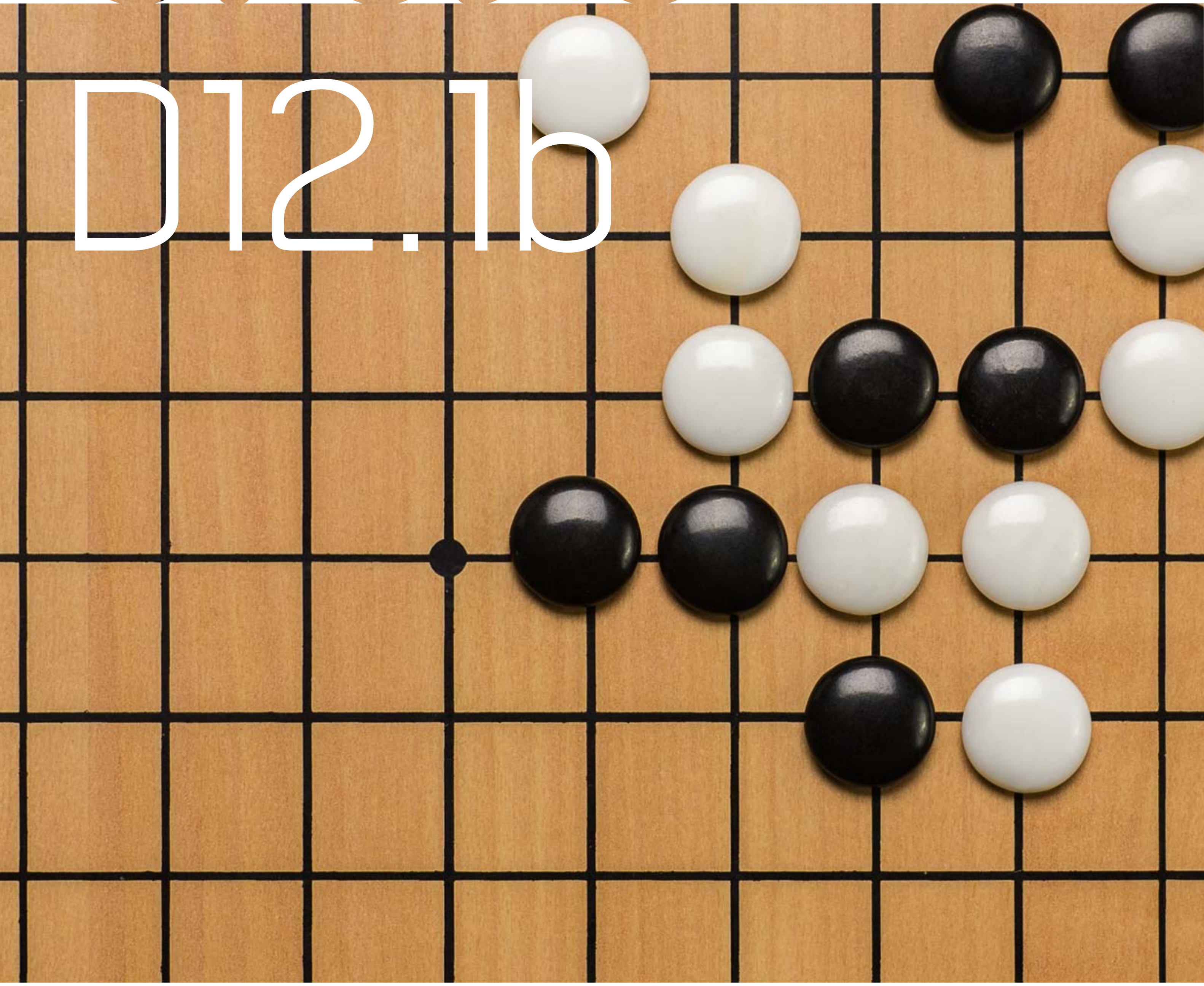

# D12.1b

TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW

# Review on flexible UWCS and transitional pathways - D12.1b

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# 1. INTRODUCTION

The past two decades have seen a growing number of calls for 'paradigm shifts' in water management – i.e. fundamental and widespread shifts in thinking around how we approach the management of water resources. Pahl-Wostl et al. (2011) argue that such shifts are indeed underway. They contend that there is a growing appreciation of the complexity of water management systems and a recognition that water 'problems' can never be treated in isolation from their social context. This is evidenced in part by the shift in emphasis from 'government' to 'governance', which highlights how current thinking has moved beyond 'command and control' approaches, and towards a greater understanding of water management systems as multi-level, multi-actor and poly-centric. However, while such paradigm shifts may be underway, they still have a long way to go.

Chapter 2 of this document aims at presenting a general overview of resilience and transition processes providing a broad review of key concepts in academic literature. It outlines some of the significant developments in theories of complex systems (e.g. socio-ecological systems, socio-technical systems, panarchy), which provides a foundation for current thinking around building resilience and managing transitions in such systems.

Chapter 3 examines how these ideas have been applied in a water management context.

In addition to the overall recognition of the importance of infrastructure and technology processes for the provision of Urban Water Cycle Systems (UWCS) to urban populations, Pahl-Wostl et al. (2011) point out that there is an ongoing dominance of technical over social perspectives in water management literature. They argue that:

> *Publications in water-related science exhibit a decisive emphasis on technology over governance. This, despite overwhelming recognition that many water related problems have their origin in governance failure!*

In order to help rectify this imbalance within TRUST, the application of the concepts of resilience and transition to the water sector is then divided into governance and technical issues, which is also in compliance with the UWCS sustainability definition for TRUST that considers those two dimensions (assets and governance) as required supporting dimensions. The governance issues addressed include policy and regulation, financial mechanisms and water service organisation and management. Technical issues address the main infrastructure components of the UWC, namely water supply, urban drainage and wastewater treatment, as well as asset management issues.

# 2. GENERAL OVERVIEW OF RESILIENCE AND TRANSITION

## 2.1. Complex systems

Urban Water Cycle Services (UWCS) are increasingly seen as highly complex systems that bring together human, ecological and technological components. As a result, contemporary thinking about the behaviour of such complex systems has a significant influence on debates about the future of UWCS. Specifically, urban water services can be seen as socio-ecological systems (SESs) or as socio-technical systems (STSs) – two related concepts which have drawn considerable attention.

SESs (or coupled human-environment systems) are essentially holistic conceptualisations of the links and interactions between ecological systems and human (social) ones (Berkes and Folke, 1998; Young et al., 2006). These holistic ideas are not new – Gallopín et al. (1989) defined SESs as 'any system including both ecological (or biophysical) and human components, ranging in scale from the household to the planet' (cited in Gallopín et al., 2001). Similarly, STSs essentially reflect a holistic understanding of the links between technology and society. STSs have been defined as systems 'which encompass production, diffusion and use of technology'. They represent the 'linkages between elements necessary to fulfil societal functions (e.g. transport, communication, nutrition)', technology playing a crucial role in that sense (Geels, 2004). These two ideas (SESs and STSs) clearly overlap – both illustrate the extent to which ecological or technological components are intricately intertwined with human components such as policy, institutions, knowledge and culture.

Understanding UWCS in this way sheds greater light on understanding how and why such systems change, and how we might facilitate change in a favourable direction.

## 2.2. Panarchy

One concept that has been used to theorise the evolving nature of complex systems (particularly SESs) is that of 'panarchy'. The term panarchy (e.g. Holling, 2001; Gunderson and Holling, 2001) is used to describe a hierarchical structure of systems, ranging from very small-scale systems (e.g. a single leaf or a single family) to very large scale ones (e.g. biomes or global economies). Moreover, these systems are nested – i.e. the smaller scale systems sit within larger-scale ones. This multi-level (or multi-scale) perspective is key to understanding the behaviour of the overall 'panarchy'.

The literature on STSs has adopted the terms niche, regime and landscape to describe these different levels or scales (see Figure 1). The term 'niche' refers to the smallest levels, encompassing individual actors and localised practices. The term 'regime' refers to mid-levels, encompassing the institutions, rules and norms that are 'assembled and maintained to perform economic and social activities' (van der Brugge and Rotmans, 2007). The term 'landscape' refers to broader societal trends, ranging from physical trends (e.g. the existing built environment and patterns of infrastructure), to economic (e.g. oil prices), to socio-cultural trends (e.g. emigration) (Geels, 2002). The relationships between these different levels – i.e. how change in one might affect change in others – will be discussed in greater detail in the section on transition management.

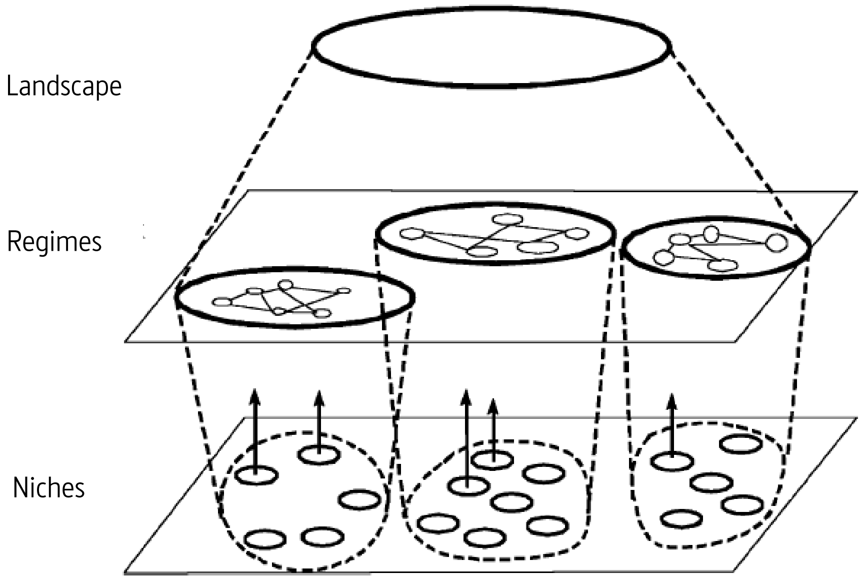

*Figure 1 Multi-level, or nested, perspective of socio-technical systems (reproduced from Geels 2002)*

In the concept of panarchy, each system within the nested structure undergoes a continuous cycle of growth, accumulation, restructuring, and renewal. These cycles include longer periods of slow resource accumulation and relative stability, as well as periods of sudden collapse and rapid reorganisation, which are often triggered by 'agents of disturbance'. These periods of collapse and reorganisation provide opportunities for innovation and novel recombination of the systems resources. The entire cycles can take place over a range of time periods, with lower-level systems (niches) undergoing more rapid cycles, and higher-level systems (landscapes) undergoing much slower ones.

While this characterisation of change is highly abstract, it can nonetheless provide significant insight into the behaviour of such complex systems. As Holling (2001) points out:

> *If we can understand these cycles and their scales, it seems possible to evaluate their contribution to sustainability and to identify the points at which a system is capable of accepting positive change and the points where it is vulnerable. It then becomes possible to use those leverage points to foster resilience and sustainability within a system.*

According to Young et al. (2006) there is still a significant and growing need to understand these 'leverage points' within SESs. They argue that:

> *In seeking to understand (and modulate) these complex and uncertain coupled systems, we need to move beyond conventional notions of risk, stability, and control, and instead shift our attention to the dynamics of resilience, vulnerability, and adaptability.*

In the context of urban water services, some indications of such a shift in thinking – away from conventional ideas of risk and stability, and towards more dynamic concepts of vulnerability, resilience and adaptability – are beginning to appear. However, as the sections below will illustrate, in many ways this shift is still in its infancy.

## 2.3. Resilience and adaptability

The concept of resilience is long established in the study of ecosystems. Holling (1973) defined it as the measure of a system's capacity for shock absorbance – i.e. its ability to absorb disturbance and persist, largely unaltered. Since that initial understanding was established, the term's usage in academic literature has evolved considerably. More recently, the concept has been reviewed by authors such as Walker et al. (2004), Folke (2006), Brand and Jax (2007) and Folke et al. (2010). These reviews illustrate significant shifts in the understanding of resilience, which are intricately linked to shifts in the understanding of complex systems in general.

In ecology, Holling's work in the 1970's essentially tried to redefine the behaviour of complex systems. According to Folke (2006) ecological theory was then dominated by the idea that ecosystems had a single, relatively fixed point of equilibrium – one 'steady state'. As a result of this assumption, resilience was generally seen in terms of recovery from disturbance – i.e. the time it takes an ecosystem to return to its steady state. This was referred to as 'engineering resilience' (Folke et al., 2010). Holling (1973) sought to challenge that assumption, proposing instead that ecosystems had multiple 'domains of stability', or multiple steady states. He also argued that systems could (and did) shift between these alternate states. Holling therefore viewed ecosystems as fundamentally dynamic – 'disturbance' was the rule rather than the exception, and in response to it systems were continually changing and developing. This concept was related to 'ecological resilience', which, in principle, 'can be measured by the magnitude of the perturbation that can be absorbed before the state of the system falls outside its domain of attraction' (Gallopín, 2006).

These ideas about the resilience of ecological systems likewise affected how other complex systems were understood (including SESs and STSs). For instance, Adger (2000) drew on these ecological concepts to develop an understanding of social resilience, which he defined as 'the ability of groups or communities to cope with external stresses and disturbances'. In general, this definition seems to reflect the more established 'shock absorbance' understanding of resilience. However, other definitions illustrate a departure from this stance. For instance, some have argued that resilience is a system's capacity to absorb disturbances *and reorganise itself into a better configuration*, while still retaining its fundamental characteristics (Walker et al., 2004). To return to Holling's theories, this reorganisation might allow a system to remain within its current domain of stability, or it might precipitate a more fundamental transformation – i.e. a shift to a new domain.

In other words, a resilient system does not necessarily 'absorb' a disturbance and return to its previous state. Instead, a resilient system is more in a perpetual state of flux, so that it can continually adjust and adapt to new disturbances and a changing context. The concept of resilience is therefore at the cusp of change and continuity – a dynamic interplay of disturbance and reorganisation (Folke, 2006). Furthermore, from such a perspective, any disturbance can be seen as a window of opportunity for creativity and innovation within systems (Folke, 2006; Folke et al., 2010).

There is still some murkiness around such abstract ideas, and there are still relatively few empirical studies that explore them in real-world examples of SESs and STSs (some empirical studies that do exist are discussed further below). However, some normative recommendations for building more resilient management systems have been put forward. For instance, Olsson and Galaz (2009) suggest that building resilience involves:

- Incorporating uncertainty and surprise – i.e. more than simply trying to reduce uncertainty, this implies accepting that knowledge will never be perfect, and that unforeseen changes are inevitable;
- Enhancing learning and supporting experimentation – i.e. allowing room for innovative management approaches, and learning from the outcomes of such approaches; and
- Facilitating participation and collective action – i.e. providing opportunities for interactions, and helping to build the skills for cooperation.

The relations between the concepts of resilience and adaptability are unclear because of the diversity of different author's views. According to Walker et al. (2004), adaptability is the capacity of the social components in a system to manage ecological resilience. It includes changing the state of the system in order to move deeper into a desirable basin or closer to the edge of an undesirable one. However, some other authors equate adaptability with resilience (Gallopín, 2006). What it is clear is that resilience is so closely tied to the idea of adaptability, that the two terms are sometimes used interchangeably. Both concepts are measures of a system's ability to reorganise itself in a beneficial manner – i.e. so that the new configuration is better suited to the context than the previous one.

## 2.4. Transition management

The fundamental challenge within all of these ideas was aptly highlighted by Olsson and Galaz (2009) who asked whether societal transitions towards more resilient, adaptive management approaches can be centrally steered. The concept of transition management (TM) seeks to address this central question. Like adaptive management (AM), TM is ultimately rooted in Holling's ideas around complex adaptive systems, but it is more specifically associated with the literature on socio-technical systems (STSs), rather than socio-ecological systems (SESs). TM literature seeks to understand how and why STSs change, and whether such changes can be 'pushed' in a favourable direction – i.e. towards sustainability.

As previously mentioned (see Figure 1), STSs are seen as nested systems, consisting of niches (individual actors and localised practices), regimes (institutions, rules and norms) and landscapes (broader societal trends). Some have argued that 'transitions' occur only when changes at all three levels can combine and compound on one another in order to push the overall system into a new configuration (van der Brugge and Rotmans, 2007). Furthermore, as Voß et al. (2009) point out:

> *Transitions to sustainability consequently imply a destabilizing of existing socio-technical structures as well as nurturing alternative systems that can fill the opportunities created by structural change.*

Rotmans et al. (2001) describe four conceptual phases in a transition process: 1) a pre-development phase, or relative stability under the status quo; 2) a take-off phase, wherein small-scale changes occur and the state of the system begins to shift; 3) a breakthrough phase, wherein visible structural changes take place through an accumulation of socio-cultural, economic, ecological and institutional changes that react to each other; and 4) a stabilisation phase, wherein the speed of change slows and a new status quo emerges. Rotmans et al. (2001) also point out that the transition process can be spurred from the top down (initiated from the landscape or regime level) but can also be driven from the bottom up (initiated within the niche level). They argue that:

> *Certain innovations in technology, behaviour, policy and institutions do break out of the micro [niche] level, if they stabilize into a dominant design around which learning processes take place. With the proliferation of the design comes a support basis – and, as a result, the momentum for take-off at the meso [regime] and macro [landscape] level. Alternatively, such a take-off at the micro level can be stimulated through developments at the meso and macro level (for example, a change in ethics, institutional changes and changes to regimes).*

These scenarios illustrate the importance of learning within a transition process. As with resilience and AM, the TM literature highlights the need to foster innovative and flexible options for policy and management, the need to treat such options as experiments, and the need to learn from and act on those outcomes. As Olsson and Galaz (2009) point out, these trial and error processes involve:

> *… the consideration of a range of future outcomes, the weighing of probabilities, small-scale pilot projects, actions designed to be useful across a range of potential futures, reversible actions favoured over irreversible ones, results monitoring and, accordingly, policy modification.*

Therefore, TM is ultimately about instigating more 'reflexive' approaches to governance and policy making (van der Brugge and Rotmans, 2007). Crucially, however, a TM approach is not about fixing particular objectives, and then experimenting with options to achieve those objectives. Rather, the objectives themselves should be 'moveable goalposts' – i.e. subject to regular re-evaluation and adjustment. Additionally, these objectives and visions for the future should be 'determined socially, not just by expert scientific knowledge' (Rotmans et al., 2001).

## 2.5. Transitions towards resilience

Foxon et al. (2008) compared theories of resilience and adaptive management with theories of transitions management. They point out that these ideas are not synonymous, and that there are a number of key distinctions between them. However, they also acknowledge that there is considerable overlap between them, and that they have a great deal to offer one another if used complementarily.

The organic nature of these ideas means that there is no definitive road map for bringing about a beneficial transition, and no concrete measures detailing what a resilient urban water system might look like. Based on the understandings outlined above, a 'transition towards resilience' would be uniquely tailored to the context and structure of the system in which it occurs. Developing a specific set of 'best practices' applicable in all contexts is therefore not feasible. However, a growing number of studies have explored the application of these concepts in the real world, and from these explorations some general lessons and recommendations have emerged.

One of the broadest lessons concerns rethinking what a management intervention actually consists of. If we see urban water management as a complex socio-technical or socio-ecological system, encompassing a multitude of actors spread across many levels of authority, comprehensive prediction and control of such a system becomes infeasible. As Pahl-Wostl et al. (2011) point out:

> *The extent to which we can talk of the 'management' of complex adaptive systems is therefore also questionable. Control is arguably replaced by influence, and imperative by meaningful engagement.*

The search for appropriate management interventions therefore also becomes a search for 'leverage points' (Holling, 2001) – points where influence and engagement can have the greatest effect in terms of guiding the system's trajectory.

However, some have put forward guidelines to facilitate transitions in a more centralised manner. For instance Voß et al. (2009; following Loorbach, 2007) argue that designing a transition requires five steps: 1) establishing a transition arena (i.e. a platform for transition-oriented interactions amongst different actors); 2) developing visions of the future; 3) backcasting transition pathways; 4) experimenting with options; and 5) monitoring, evaluation and revision. Moreover, this approach was developed and implemented in the Netherlands, starting around 2001 when the Dutch government adopted a national environmental policy which instigated a number of 'transition projects' (Voß et al., 2009; Foxon et al., 2008). These managed transitions took place in a variety of different sectors including energy (Kern and Howlett, 2009), waste (Kemp, 2006), and water (van der Brugge and Rotmans, 2007; van der Brugge et al., 2005). According to analysts, these efforts have met with mixed degrees of success, some examples of which will be discussed further below.

Additionally, Meijerink and Huitema (2009) have drawn together a number of case studies from around the world which illustrate transitions in water management. While they, too, acknowledge that 'one size does not fit all' in terms of instigating change in the status quo, their analysis does draw out a number of strategies that 'policy entrepreneurs' (actors that champion change) use to drive transitions forward. These include using narratives to frame issues strategically, in order to justify change and attract supporters; balancing strategies of advocacy and brokerage between different interests; and developing and testing attractive policy alternatives in order to demonstrate their relative feasibility. One of their key findings concerned the importance of 'collective policy entrepreneurship' – wherein networks of actors (rather than lone actors) work together to drive a transition forward. The main advantage of the collective approach is that different actors can draw on different sets of knowledge and skills, and on different arsenals of strategies and opportunities, making the network as a whole more effective at instigating change.

In other words, there is some abstract guidance on implementing these ideas in the real world. However, this also raises a number of dilemmas. For instance, resilience and transitions approaches rely on experimentation with different options, and the ability to learn from, and adjust to, the results of those experiments. This requires keeping a wide range of options open, and avoiding 'lock in' to particular technologies or pathways. However, large-scale infrastructure projects often require long-term commitments and fixed investment, which reduces flexibility and necessitates lock in (Voß et al., 2009). There are no easy solutions for such dilemmas.

# 3. RESILIENCE AND TRANSITIONS IN THE WATER SECTOR

## 3.1. General aspects

This section intends to examine how these ideas of resilience and transition have been applied in a water sector context in what concerns governance and technical issues.

For governance issues, the review focused mainly on empirical case studies situated largely within the resilience and transitions literatures (rather than in the more general water management, governance and sustainability literatures). The purpose was to explore: a) how ideas of resilience and transitions have been applied (if at all); b) what evidence exists (if any) regarding the benefits and pitfalls of applying such ideas; and c) what lessons (if any) might be drawn for their application in the context of urban water services. The review is not meant to be exhaustive, but to highlight the examples that offer the most evidence regarding how these ideas have been, or could be, applied to water sector.

In what concerns technical issues, it should be noted that the physical characteristics of an infrastructure are defined during design, in order to meet a specific level of service, or a range of service levels. Its capacity and operating range is, therefore, known to the utility manager and can only be stretched to a certain point if no intervention is made. In this context of operating range, physical infrastructures have what can be referred as "engineering resilience" (Holling, 1996), in the sense of its ability to recover from shock and return to the same operating condition ("stabilty point"). The change to an operating condition outside the limits of the operating range as in an adaptive process is a capacity that infrastructures by themselves do not have. This change can only be achieved through actions taken by the other actors of the system. As pointed out by Blackmore and Plant (2008), "ultimately, adaptive capacity resides in institutions and individuals rather than in physical system parts such as pumps and pipes". As such, in this report, the concept of resilience as applied to infrastructures will be made in the sense of identifying key technologies that address specific needs and how they can enable resilience of the system and thus a transitioning towards a more sustainable condition.

The review also examined some of the 'grey literature' from the UK water sector[1].

## 3.2. Governance issues

There is a modest body of empirical academic literature that explores the application of resilience and transitions in water management, and this body is growing. The following sections use some of the key relevant case studies to explore the three questions noted

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[1] The focus on the UK was largely due to the availability of documents published in English.

above, in the context of different components of urban water systems – namely policy and regulation, finance, and water service organisations.

### 3.2.1. Policy and regulation

In the Dutch case, as previously mentioned, a widespread 'managed transitions' approach was instigated through national environmental policy. The key function of this national policy was to 'destabilise' the status quo by formally illustrating the need for a new direction. The policy also created forums (i.e. transition arenas) that drew together a wide range of actors, who would develop visions of the future and transition pathways for different sectors. These forums could therefore help to build linkages across the different levels of the socio-technical system – i.e. linking niche-level innovation with regime-level direction. The forums could also establish bridges between different 'ways of knowing' about water (Ingram and Lejano, 2009) – different fundamental perspectives on, and approaches to, water management – thereby maximising opportunities for learning and developing innovative options.

However, the transitions approach in the Netherlands has been criticised by some. For instance, in the energy sector, efforts to destabilise the status quo may have been undermined when the Dutch government allowed the transition arena to be overseen by the country's dominant energy corporation (Shell Netherlands). As a result, some argue that the capacity for radical innovation in the sector is vastly diminished and that already-dominant views could simply be reasserted (Voß et al., 2009; Foxon et al., 2008). This illustrates a key issue within transition management – i.e. while it is important to bring together a wide range of actors and 'ways of knowing', it is crucially important to be aware of (and perhaps redress) the power imbalances between those actors, in order to prevent the transition from being 'captured' by those with interests in maintaining the status quo.

As previously discussed, the concept of resilience implies capacity for creativity and innovation, and for learning from experience, in order to facilitate system reconfiguration. In the Dutch water sector, there has been a significant shift in regime-level priorities, so that water management (and particularly the perspective of habitat protection) is now a 'guiding principle' in spatial planning (van der Brugge et al., 2005). This transition process has seemingly prompted considerable innovation and experimentation with new management options. However, some argue that there is still little coordination to bring together the outcomes of these experiments and learning experiences (van der Brugge and Rotmans, 2007). As a result, the transition process in the water sector appears stuck in an early phase, unable to coalesce into a new regime. This is another aspect where policy and regulation could play a role – building linkages between different niche-level experiences, in order to facilitate a broader learning process.

Another relevant case study is the California San Francisco Bay/San Joaquin Delta water management programme (known as CALFED), which has been thoroughly researched in the literature. CALFED began around 1994 as a self-organising, informal initiative (i.e. not the direct result of a policy intervention) which involved government agencies, municipalities, NGOs, and a variety of other actors. It was primarily a means of dealing with the frequent conflicts and stalemates that arose over how to allocate the region's scarce water resources. It became a largely informal decision-making arrangement, with no fixed set of actors, and with a number of innovative governance features, including a distributed network structure, collaborative interaction heuristics, and a non-linear planning method (Booher and Innes, 2010).

Over the years, CALFED has become one of the most lauded examples of a flexible, informal governance arrangement based on principles of collaborative and adaptive management. Some argue that policy and regulation ought to lay the groundwork to enable and encourage such self-organising initiatives (Olsson and Galaz, 2009), and that they can improve the resilience of socio-ecological systems (Booher and Innes, 2010; Olsson et al., 2004; Olsson et al., 2004). However, it is unclear what kind of institutional structures might support the creation of initiatives like CALFED (Kallis et al., 2009), and the evidence that they do indeed improve system resilience is still sparse. Additionally, while CALFED has had many successes, it also has limitations. For instance, Kallis et al. (2009) point out that while CALFED supported the development of innovative management measures in principle, in practice many radical options may have been sidelined for the sake of achieving consensus between stakeholders. Additionally, they argue that there are some fundamentally conflicting objectives in the region (environmental restoration vs. further development) which CALFED cannot hope to resolve – such difficult decisions and tradeoffs must ultimately be the responsibility of government.

### 3.2.2. Financial mechanisms

There is a vast amount of literature on the use of different financial incentives to support sustainability objectives in the water sector. This literature covers water supply metering, the use of different tariff structures for water consumption, and other forms of financing for water service providers and water users. The general consideration is how such financial mechanisms can be used to incentivise more sustainable technologies and behaviours. These debates, particularly those concerning metering and water pricing, can be intricately bound to questions of social equity – i.e. what poorer households can afford in terms of water tariffs or water saving technologies (Dresner and Ekins, 2006; Bakker, 2001). However, few of these financial mechanisms have seemingly been explored specifically from the perspectives of resilience or transitions.

One relevant example, however, stems from CALFED, which resulted in a scheme known as the 'environmental water account' (EWA). The EWA was similar to a tradable permits scheme, and it enabled some stakeholders to acquire (through voluntary sales and agreements) water rights to support endangered species protection in rivers and wetlands. This environmental water supply could then be 'held' in reserve, to be used when needed most, thereby minimising the disruption to other water users (namely farmers and municipalities). The scheme relied heavily on the transparent collection and analysis of reliable environmental data. The EWA was arguably one of the most successful schemes that emerged from CALFED – it had a significant effect on the availability of water for species protection, and the scheme remained operational even when the CALFED partnership itself was effectively dissolved. One of the scheme's key strengths was its flexibility, which enabled participants to anticipate and proactively adjust to changing conditions and water needs, rather than simply reacting to them (Booher and Innes, 2010).

Similarly, Walker et al. (2009) have argued that resilience in Australia's Murray basin could be improved by instituting a more flexible water trading scheme, particularly one that facilitates trade between states. They also argue for a number of other shifts in financial incentives – namely removing incentives that encourage excessive water storage, and increasing incentives to farmers to improve water quality and conserve wetland habitat. However, any empirical assessment of whether such measures could improve resilience is still lacking.

### 3.2.3. Organisation and management

Once again, there is a vast amount of literature that examines the structures and governance of water service organisations, and some of this explores how they have been (or could be) reformed to support sustainability objectives. However, there is seemingly no literature that has specifically explored the application of resilience and transitions ideas within water service organisations.

Nonetheless, there is some evidence which speaks to the potential application, as well as the benefits and pitfalls, of these ideas. For instance, the sheer diversity of water service organisations in European provides a good foundation for experimentation with innovative measures. In the UK, different corporate structures exist in England (wholly private, regulated water companies), Scotland (a public corporation) and Wales (a not-for-profit organisation). Some research (e.g. Bakker, 2003) has sought to compare some of these different structures, and examine their relative advantages. From a resilience perspective, these models (as well as others across Europe) can be treated as *de facto* experiments. Water service organisations can therefore look to one another's experiences and draw lessons from more innovative models.

Such interactions certainly do take place. For instance, some English water companies have recently been experimenting with sustainable land management initiatives. These schemes generally involve working directly with land owners and managers (e.g. farmers) in order to directly address the causes of certain forms of pollution, thereby decreasing the need for more costly forms of water treatment. Those companies that have implemented such schemes have recently been encouraged to share their experiences with other companies who are looking to adopt them. This is a clear example of how water service organisations can actively seek to learn from one another's innovative measures, in order to facilitate their own reconfiguration.

However, there is also some evidence of the pitfalls of such ideas. For instance, a resilience perspective advocates the need to accept that some uncertainty is inevitable, and to 'keep options open' as long as is feasible in order to maintain flexibility and maximise learning opportunities from different approaches. As previously mentioned, this creates tension within the water sector where large-scale infrastructure projects can require long-term commitment and certainty of investment. This tension is illustrated in Scottish Water's most recent delivery plan (SW, 2011), which outlines the risks the company faces as a result of some uncertainty around the future of their Billing and Collection Order (which governs their ability to bill customers). An approach that advocates accepting uncertainty and 'keeping options open' could be perceived as a very risky one within water service organisations.

## 3.3. Technical issues

The technical issues in the UWCS in the context of resilience and transition will be addressed in four main domains: the three main components of the UWCS infrastructures, namely, water supply, urban drainage and wastewater treatment, and the issues of asset management.

### 3.3.1. Water supply

Water infrastructures should also become more resilient to potential pressures like the effects of excesses or shortages of water. In fact, all drinking-water technologies are vulnerable to pressures and all have some adaptive potential. For instance, shallow groundwater systems, roof rainwater harvesting and some surface waters are vulnerable to extended dry periods. On the other hand, deep or old aquifers that have long recharge times are likely to feel lower impacts. Piped distribution networks are at risk of contamination where more frequent flooding occurs, and may become more intermittent in drying environments. Tubewells are the most resilient of these technologies. Protected springs and small piped supplies have medium resilience (WHO, 2009).

In order to increase preparedness to meet future needs in water supply systems, one of the main issues that should be considered is securing supply. It involves two main issues: more diversity and alternative supplies, and increased storage capacity. Even in the presence of demand-side strategies to reduce water consumption, when demand still exceeds water availability, alternative supply sources need to be considered. Diversifying water supplies prevents an overreliance on just one source and therefore reduce risks of water shortage (Ingham et al., 2007) and a region's over-reliance on a single source of imported water (Loftus, 2011). Furthermore, the purpose of storage is to capture water when and where its marginal value is low – or, as in the case of floods, even negative – and reallocate it to times and places where its marginal value is high (Keller et al., 2000). Apart from classical surface and groundwater resources and water recycling, alternative or remote water resources may also be used. These mostly include waters of less raw qualities and the use of remote water sources, which justifies the importance of considering the water transport (Staub and Golvan, 2011). Figure 2 ilustrates the interconnection between these main issues in securing supply.

Alternative water resources in the city could be developed through supply planning like rainwater, stormwater, wastewater, groundwater, desalination (SWITCH, 2006). Rainwater, stormwater and wastewater may be used to the injection into aquifers (Aharoni et al., 2011). The groundwater recharge, together with augmentation of reservoirs will contribute to increased storage capacity. Water stored in the aquifer can then be pumped from below ground during dry periods for subsequent reuse, thereby providing another alternative to large surface water storages (JSCWSC, 2009). Finally, besides the usual piped water, water transportation might be also needed during water crises in the form shipment.

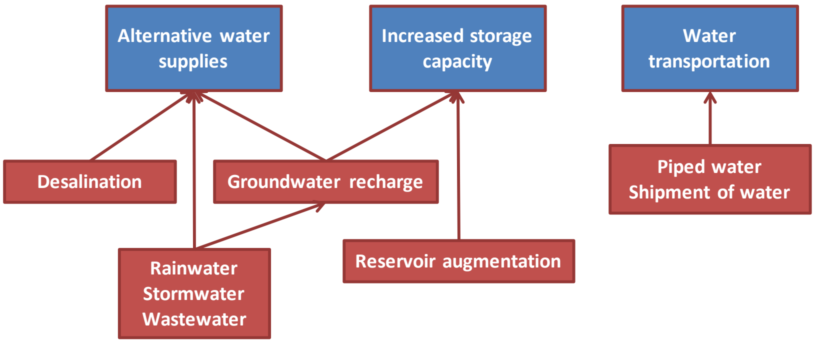

*Figure 2 - Relevant option that provide flexibility and resilience to secure water supply*

*Rainwater harvesting* (RWH) refers to the practice of collecting rainwater from roofs or other impermeable surfaces. In most cases a more or less simple water treatment is added, at least lead screen or more elaborated filters (Staub and Golvan, 2011). It reduces stormwater discharges and water consumption as well as the need for groundwater extraction (Ellis et. al., 2006). Although there is no doubt that RWH saves water, its massive use as an alternative to an existing reliable water mains supply may not be sustainable regarding carbon emissions (due to tank-embodied $CO_2$ as well as an unsatisfactory pump efficiency) (Way et al., 2010). In Germany, the Federal Environmental Agency encourages the harvesting of rainwater for garden use, but has warned that the indoor use may comprise health risks and be economically inefficient (Staub and Golvan, 2011).

Stormwater is the rainwater collected from a given infrastructure such as a large building complex or a transportation infrastructure (Staub and Golvan, 2011). In order to combat the expected increased frequency and intensity of storm events, one should consider investing in various forms of stormwater *retention, infiltration or use* (SWITCH, 2006). Storm water runoff harvesting (SWH) consists in collecting, storing and reusing stormwater collected from drains or creeks, on the contrary to RWH, where rainwater is directly collected from roofs. SWH is particularly common in Australia and New Zealand, but in general it remains a relatively neglected water resource. Urban runoff may be polluted with organic matter, pesticides or heavy metals, which effects and fate remain unknown (Staub and Golvan, 2011).

*Water recycling* encompasses the reuse of water as a potable or non-potable secondary source, after having been retreated accordingly. It reduces demand for fresh water resources, diversifies the water sources and reduces the volume of wastewater discharged into the environment (Staub and Golvan, 2011). Direct non-potable reuse of wastewater (e.g. irrigation, dust control, fire suspension) can be based on greywater (residential wastewater originating from clothes washers, bathubs, showers and bathroom sinks) or various other wastewater reuses (Leflaive, 2009), but there is still the recognized need of a unified European regulation for quality standards (Staub and Golvan, 2011). Direct potable reuse (DPR) of wastewater involves the reuse of treated wastewater without dilution with other sources or types of water. It often triggers public debates due to the lack of public acceptance. The negative term "toilet to tap", born in 2001, lead to a failed project in Los Angeles due to public revulsion. The only example of large-scale DPR worlwide currently in operation is located in Namibia, due to local water scarcity and arid climate conditions (Staub and Golvan, 2011). Finally, Indirect Potable Reuse (IPR) of wastewater is related to the planned reuse of treated wastewater after dilution with other types of water (e.g. via groundwater recharge). In Berlin, Germany, the municipal water supply relies for 70% on bank filtrate, with proportions of treated wastewater ranging from 10-30 % in the drinking water (Moller and Burgschweiger, 2008). Although public acceptance is higher than for DPR, IPR must also be accompanied by a consumer information and education campaign. In Australia, early plans included IPR from the 1990s, but due to public reluctance, most projects are still under development (Marsden and Pickering, 2006).

*Aquifers* are an important water source in many European regions, especially in the Mediterranean area, many of them being already under stress due to a growing demand. Their viability to store water volumes from non-conventional sources during periods when supply and demand are not balanced is very important. However, there are two key impacts that may affect aquifers: sea-level rise as a consequence of increased temperatures, inducing saline intrusion into aquifers; and a change in the rainfall patterns, meaning that less water will be available for aquifer recharge (WssTP, 2010). In order to face sea water intrusion in coastal aquifers and coastal lakes, barriers might be built (Staub and Golvan, 2011). In what related the challenge of changes in rainfall patterns, it has to be noted that groundwater renewal can be enhanced by stormwater infiltration (Ellis et. al., 2006) but also through aquifer recharge management (like the Soil Aquifer Treatment), in which water is intentionally introduced into an aquifer in order to store excess water during the rainy season to be used in dry periods, to introduce a barrier for treatment of water and to reduce the risk of intrusion of impaired water (e.g. in coastal aquifers) (Aharoni et al., 2011). Adapted land-use management can also constitute a useful solution to preserve high infiltration capacities of natural grounds, besides the fact that it is a long-term adaptation policy, which goes beyond the borders of urban planning (Staub and Golvan, 2011). In addition, flood defences for groundwater recharge may also be considered, especially flood retention basins and ponds, which naturally enhance the recharge of groundwater if they are constructed on permeable terrain (Staub and Golvan, 2011). In California, flood control facilities were converted into aquifer recharge facilities in order to avoid the new construction of ponds and associated land use change (Campbell, 2011). Note that the implementation of multi-functionality of equipments is a way to keep investment costs acceptable by covering several functions with a single equipment, and at the same time, it saves space, which is essential in urban areas (Digman, 2010). However, experience has shown that multifunctional equipments need alteration, which may induce additional costs for the initial design or adaptation of the equipments (Staub and Golvan, 2011). At last, Aquifer Storage and Recovery, also referred to in some areas as Managed Aquifer Recharge (MAR), is another mean of enhancing water recharge to underground aquifers (JSCWSC, 2009). As it percolates down into the aquifer, it is usually purifies of biological pollutants. Being an underground storage solution, it does not require large surfaces of land as it does reservoir storage (Keller et al., 2000). It is however dependent on local hydrology, the underlying geology of an area and the presence and nature of aquifers (JSCWSC, 2009). Among other potential difficulties, infiltration basins may not be implemented directly in urban areas due to the pollution risk. Protection measures for the underground storage must be taken in order to preserve it. There is also a lack of guidelines for the quality of infiltrated water (Staub and Golvan, 2011). Some examples may be presented: in Delft, the Netherlands, underground storage and infiltration basins have been retrofitted to existing public spaces within the urban area (Digman, 2010). The Torreele reuse plan on the Flemish Coast in Belgium reuses wastewater effluent for groundwater recharge of an unconfined duce aquifer since July 2002. The injection of the treated effluent enabled to reduce by more than 60% the salinity of the dune aquifer, and led to higher groundwater levels (Staub and Golvan, 2011).

Other option for augmenting and diversifying available national water sources in coastal regions includes the *desalination of seawater or brackish water* for reuse (Retamal and White, 2011). The most utilised desalination technologies are thermal distillation, membrane separation freezing and electrodialysis (Khawaji et al., 2008). Desalination of brackish water usualy uses water from deep saline aquifers, brackish springs or other sources of brackish water (Staub and Golvan, 2011). However, desalination consumes large amounts of energy and the discharges of high salinity reject water into the environment potentially harm coastal and marine aquifers (Novotny et al., 2010). Furthermore, technology costs are expected to increase because of project site location and environemental considerations (Carter, 2011). On the Maldives Islands, solar desalination plants are being built to supply freshwater while decreasing the dependency on fossil fuels and GHG emissions. Several coastal cities of Europe, Northern America and Australia have also considered sea water desalination in order to diversify the supply options. In Egypt and Jorfan, brackish water desalination already covers up to 10% of the total country's freshwater demand (Staub and Golvan, 2011).

The storage in reservoirs (dams or impounded rivers) is the most popular traditional option. Nevertheless, disadvantages of dams should be taken into account, namely evaporation losses, sediment accumulation, potential of structural failure, increased disease and adverse environmental effects (Wasimi, 2010). *Augmentation of reservoir storage* is an important alternative. For example, in South-East England, seven large-scale water storage facilities are being considered to increase storage capacity by 2020 (Strosser et al., 2007).

If no local water sources are available, or if they do not cover the local demand, water can be transported from a remote location either continuously (i.e. via a pipeline) or punctually (i.e. shipment of water). *Transportation of water* shall be considered only in some identified critical cases as a last resort option, since the import of remote water may deplete water resources in other places and pose threats to the local environment. Aqueducts sometimes have high leakage rates, resulting in substantial waste of freshwater. As an emergency option, for countries facing sudden water crises, water may also be shipped using tankers.

This is what is happening in Catalonia, that has imported freshwater from the Rhône (France) several times during intense drought periods since de 2000s (Staub and Golvan, 2011). It is also worth mentioning the possibility to ship icebergs or large “pouches” of fresh water from one water-rich region to a region facing a water crise (Arnell and Delaney, 2006).

In addition to securing water supply, distinct levels of *water treatment and distribution might be considered according to uses*. The guiding principle of Integrated Resource Planning is that utility customers do not necessarily demand for a resource itself (e.g. liters of water) but rather for the services provided by water, such as clothes washing or toilet flushing. This approach opens up supply and demand management options, based on developing a mix of solutions (Kayaga and Smout, 2011). In this context, the secondary supply pipeline for non-potable water (eg. stormwater, groundwater, recycled wastewater), also called the third pipe system or dual supply, can replace the use of potable water for such uses as toilet flushing, laundry, street cleaning, garden watering and open space irrigation, thus providing a sound basis for promoting a ‘fit-for-purpose’ approach to water use. It is also a fundamental basis for preserving future opportunities for accessing recycled water and stormwater use (Wong and Brown, 2008). Furthermore, a separate system supplying this lower-quality (simply treated or untreated) water lowers the pressure on freshwater aquifers. In Australia, several cities are equipped with dual water supply systems for irrigation and street water cleaning. In Paris, such a parallel distribution network with roughly filtered water from the Seine River is used for street and sewer cleaning for more than 150 years, although the costs and the general decrease in water consumption are being considered as problems. These dual systems also bear the risk of wrong connections between the different supply systems, which can be a threat both to human health and the environment (Staub and Golvan, 2011).

Finally, multiple and complex links exist between water and energy and the intensive energy use of water infrastructure can be a drawback when cities are trying to reduce greenhouse gas emissions to mitigate climate change (Loftus, 2011). Among other things, to achieve the global goal of reducing GHG emissions implies water (energy) conservation, reuse of used water and use of stormwater, development and use of renewable energy, reduction in energy use in urban and suburban transportation and building infrastructure (Novotny et al., 2010). Technology optimization for energy consumption reduction is also very important, namely through technology innovation in the advanced management of WTP and WWTP (ex microturbines, speed variation devices). The challenge of choosing between centralized and decentralized systems is also related to the water-energy nexus. In fact, in some situations more decentralised solutions can actually increase energy consumption, highlighting the need for constructive dialogue between water and energy managers (Kenway, 2010 in Loftus, 2011).

In conclusion, the best options are context-specific. In any case, it is important to consider several technologies and infrastructures. They need to be applied effectively and efficiently, ensuring that quality of the water distributed meet the respective water quality standards.

### 3.3.2. Urban drainage

The transport of wastewater and stormwater to receiving waters can be achieved through a series of different pathways and combination of infrastructures, which interconnect and also interact with the receiving waters. The interconnections that exist in combined sewerage systems can produce significant impacts to the receiving waters during wet weather due to the discharge of combined sewer overflows (CSO), and fail to ensure that all wastewater that is produced is adequately treated in a wastewater treatment plant (WWTP) before the final discharge. Figure 3 presents the interactions between urban drainage sources, pathways and receptors, where the complexity of interrelations can be observed.

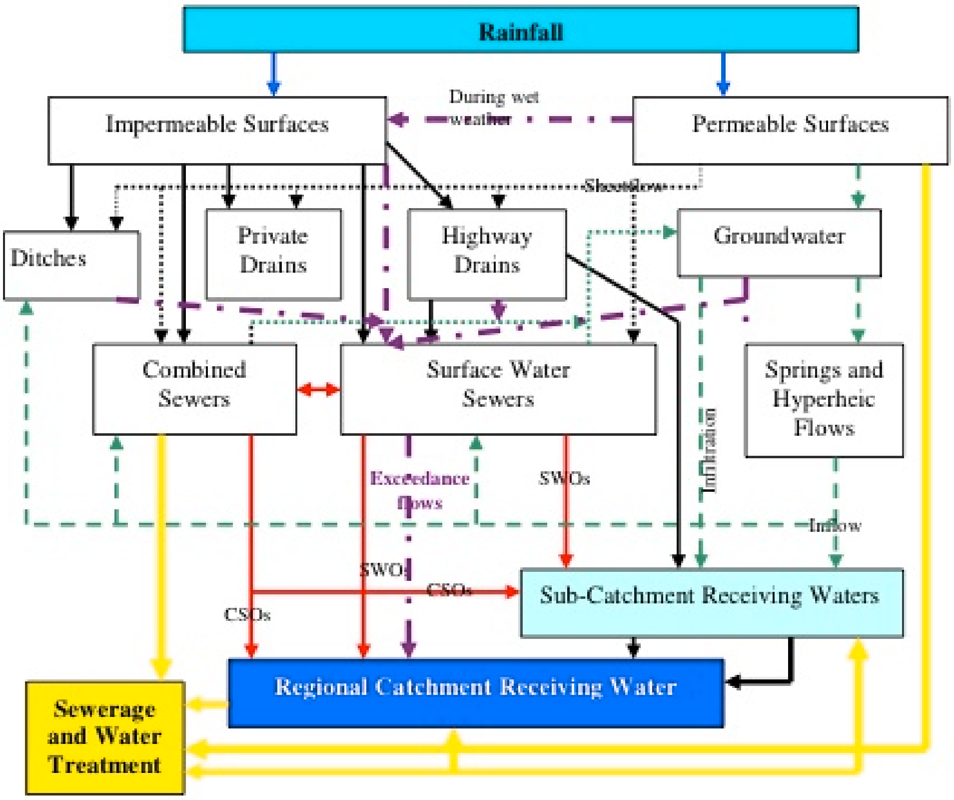

*Figure 3 - interactions between urban drainage sources, pathways and receptors (Ellis et al 2009).*

- **Best management practices for stormwater flow control**

Historically, the main objectives in the design of urban drainage systems were to ensure an efficient management of peak flows and the adequate treatment of polluted waters, in order to maintain public hygiene and to prevent flooding (Rauch et al., 2005). More recently, integrated approaches for urban water management emerged and other key issues were identified for a sustainable water management such as surface and ground water quality, ecological concerns, and recreation (Shutes and Ragatt, 2010).

In order to operationalize these concepts, in the last decades several best management practices (BMP) in urban drainage management have been developed. These BMP are mostly directed towards stromwater management practices, to face the highly variable flows and increasing pollution levels. Stormwater managment BMP have evolved from highly engineered solutions, which did not blend with the environment, to eco-engineered solutions with multi-purpose functions (Novotny et al., 2010). These eco-engineered BMP are more sustainable than traditional ones since they can provide services in the three pillars of sustainability, namely the following (Novotny et al., 2010):

- Mimic nature
- Provide and enhance surface drainage
- Repair unsustainable hydrology by reducing flooding and providing enhanced infiltration and provide some ecological base flow to sustain aquatic life as well
- Remove pollutants from the ecological flow
- Provide water conservation and enable water reuse
- Buffer and filter pollutants and flow for restored/day lighted streams
- Enhance recreation and the aesthetic quality of the urban area
- Save money and energy

Stormwater BMPs are commonly divided into structural and non-structural measures. Structural BMPs involve the construction of a physical infrastructure whereas non-structural BMPs involve either the introduction of a new management practice or the modification of an existing management practice (Ellis et al., 2006).

Some examples of structural BMPs are also classified as Sustainable Urban Drainage Systems (SUDS). These technologies consist of different modular elements, which are compatible with each other and can be replaced or changed independently. This modular characteristic enables a decentralized application which facilitates the allocation of resources to locations that are most affected by change (Eckart et al., 2011).

The SWITCH project developed extensive work on stormwater management and produced a guide presenting stormwater management BMPs (Ellis et al., 2006). Some examples of structural BMPs identified in this report include infiltration basins, porous pavments, detention ponds/basins (dry ponds), swales, infiltration trenches, green/brown roofs and swales.

Figure 4 presents pictures of four of these BMPs, being worth noting that the infiltration basin has a dual purpose since it is a running track during dry weather.

a) Infiltration basin

b) Infiltration trench

c) Porous pavement

d) Swale

*Figure 4 - Examples of structural stormwater BMPs (a) from Betess (1996) and b) and d) from Azzout et al. (1994)).*

Some examples of non-structural stormwater BMPs include the following (Ellis et al., 2006):

- Control of illicit connections (for wastewater disposal) to storm sewers
- Increasing vegetated areas to increases surface roughness, in order to control both the quantity and quality of stormwater runoff. These measures are usually applied together with others and also enhance the aesthetic quality of facilities and urban landscapes.
- Development of public education and awareness campaigns

An extensive review of non-structural stormwater BMPs can be found in Ellis et al. (2006).

The decentralized application of stormwater BMPs has been pointed by Eckart et al. (2011) as turning drainage systems more flexible, when compared to traditional, centralized options. This flexibility will enable utilities and other stakeholders to perform an adaptive management of the system. The modular characteristic of most BMPs will potentially be relevant since a transitioning pathway to achieve more sustainable urban water systems will need to take into consideration existing infrastructures, and possibly the introduction of new ones in urban areas already consolidated.

Separate sewers can also present problems in the wastewater transport component, namely when the installed transport capacity has reached its maximum and cannot accommodate an increased flow, as can occur in growing urban areas; and septicity problems in long sewages with a high residence time.

In what concerns transport capacity, these situations can be addressed by controlling sources of new flow onsite through the introduction of decentralized treatment facilities such as constructed wetlands or land treatment. This falls outside the scope of drainage, since wastewater transport needs are heavily reduced and fall under the scope of wastewater treatment, which is addressed in the next chapter.

### 3.3.3. Wastewater treatment

It is usually not common for a single technology to addresses all the issues that are relevant for each system. In this context, the combination of different technologies to achieve a given performance is a feature that can contribute to enable the system's resilience. This can be achieved by introducing additional technologies to respond to new needs. An example is when water quality needs become more stringent over time, as when a secondary treatment level needs to be upgraded to tertiary level for disinfection.

In the context of wastewater treatment, the following key targets were identified as relevant to act upon in order to improve the system's resilience:

- managing flows;
- ensuring water quality levels;
- enhancing energy saving and production;
- adopting low carbon footprint technologies.

The following sections focus on technical aspects regarding flow, water quality levels and energy, presenting potential technologies that can be adopted and their contribution to facilitate transition and enhance the system's resilience. Low carbon footprint solutions will be addressed along with the other targets.

It is relevant to point out that some of the technologies presented can be introduced gradually (decentralized ones) whereas others can only be applied if the treatment is being installed "from scratch" or when a renovation/substitution is needed as when a component's life cycle reaches its end. It is in this last context that pressures applied to a system are not always negative, since it can represent an opportunity to introduce something more sustainable, turning the system into a more resilient one.

- **Managing flows**

In some older towns sewage networks evolved form existing stormwater drainage networks, turning them into combined sewage networks and installing a wastewater treatment plant as an end-of-line treatment. Due to these characteristics, combined systems are subject to large flow variations associated with the stormwater component of the flow.

The challenge for wastewater treatment in combined sewage systems is to manage flow variations and the differences in wastewater quality, in a short period of time. Technologies for wet weather flow management inside the system need to provide a fast response to a sudden change in flow. In-system and offline techniques have been developed to achieve this, namely the following:

- Installation of two separate flow lines in the WWTP, one to operate continuously to accommodate dry weather flow and a different one to address wet weather flow
- Off-line detention and treatment, through the diversion of combined sewage from a main trunkline to a wet weather treatment facility during wet-weather conditions (Szabo et al. 2005)

As an in-system technology, real time control or storage in WWTP storm tanks can also be used to retain CSO within the system and subsequently released to the WWTP for treatment. According to Struck et al. 2009 real-time control seems to be a promising way to resolve CSO overflow problems. However, this technique is not fully consensual, since, as pointed out by Ashley et al. (2003), this option can cause late flushes (off-line), or lengthy periods of high hydraulic loading with low substrate for many days after a storm, which can reduce the WWTP treatment performance by increasing effluent concentration.

The technologies and techniques described so far are directed towards end-of-line interventions associated with centralized sewage systems. Additionally, decentralised technologies addressing stormwater managment aiming at reducing stormwater flow that enters the sewage system can also be applied, and treated locally. These technologies have been presented in chapter 3.3.2, and can be used together with in-line options. It is also worth reinforcing that decentralized BMPs technologies usually present lower carbon footprint for CSO treatment since energy use and materials is more reduced.

- **Ensuring water quality levels**

With the publication of the Water Directive Framework, attention shifted from wastewater quality at the discharge to set ecosystem-based objectives. This new framework induced an increasing need for more stringent water quality levels, which promoted technological applications to address specific needs. The classical secondary treatment providing removal of organic matter and suspended solids is being increasingly upgraded to include the removal of additional pollutants such as nutrients, bacteria or heavy metals. This additional treatment level can also be described as advanced wastewater treatment.

Sonune and Ghate (2004) propose a division in advanced wastewater into three major categories according to the process flow scheme utilized:

- Tertiary treatment - addition of unit processes after conventional biological treatment (secondary treatment);
- Physicochemical treatment - biological and physical–chemical processes are intermixed to achieve the desired effluent;
- Combined biological–physical treatment - biological and physicochemical treatments are mixed.

It is also important to point out that the increase in water quality standards for effluent discharges may create better conditions for wastewater reuse. This situation can emerge once the standard for the treated wastewater reaches a certain threshold point were the additional cost of treatment to enable a given reuse is compatible with market costs (willingness to pay) for that type of use. In fact, according to Lazarova et al. (2001), "the development and implementation of wastewater reuse practices around the world have shown that reclaimed water is a proven, reliable alternative resource, which can be sold as a new product: "*recycled water*". More stringent water quality levels can also arise from a context of water scarcity. In a water scarcity scenario protection of the existing water bodies is important in order to protect water sources. Additionally, and from the demand side wastewater reuse may also be an important option as a source of water for some type of uses.

The advanced treatment options presented above can be applied to treat wastewater to allow for different uses, but constitute a centralized approach to wastewater treatment. Additionally to these technologies, a decentralized type of wastewater treatment can be used to enhance discharged water quality.

Natural system technologies such as high rate infiltration and overland flow, constructed wetlands and waste stabilization ponds are designed to take advantage of the natural treatment capacity provided by the soil and other natural structures that exist in nature. These types of treatments, often classified as extensive treatment since no electro mechanic energy input is necessary (they use energy from the surrounding environment), are less dependent on non-renewable fossil fuel energies and on added chemicals and have low investment and maintenance costs. To reduce the required space, new technologies still need to be studied (SWITCH, 2006b). Given these features natural systems technologies are usually considered to present a low carbon footprint and some, like constructed wetlands, may even provide carbon abstraction services (Machado et al., 2007).

The decentralized nature of natural systems enables a scattered application in specific locations were traditional solutions fail. An example is the expansion of a new area in the periphery of a city, where a local treatment facility can be installed and put into operation. This modularity, which was previously pointed out to stormwater control BMPs presented in chapter 3.3.2, enables a more resilient system, and allows for an adjustable transitioning pathway were infrastructures are introduced according to needs and in specific, targeted locations close to the source.

- **Enhancing energy saving and production**

The origins of sustainability concerns were related with energy uses and a concern to reduce the consumption of fossil fuels, which also has implications on climate change. The goals set by European governments to reduce greenhouse gas emission has led that the different sectors of the economy were called to promote energy efficiency and reduced green house emissions. In the water sector the direct links between energy and greenhouse gas emissions provide an additional driving force for increasing energy efficiency, since it can also bring benefits in terms of operating costs. In fact, after manpower, energy is the highest operating cost item for most wastewater companies (Frinjs et al., 2011).

In what concerns wastewater treatment systems, there are several options not only for reducing energy consumption as well as for producing energy. Table 1 present examples of energy optimization options applied to different infrastructures and Table 2 provides examples of energy production (heat and power generation).

*Table 1 - examples of energy optimization options applied to different infrastructures in wastewater treatment systems (adapted from Frinjs et al., 2011).*

| INFRASTRUCTURE | ENERGY OPTIMIZATION |
|---|---|
| Sewerage network | Pumps: efficiency improvements, e.g. duty point and duty rate selection, variable<br>Infiltration and inflow reduction, real time control |
| WWTP liquid phase | Speed drives, inter stage pumping, reduced Returned Activated Sludge pumping<br>Aeration in WWTP: energy efficient bubble aerators, on line aeration control<br>Nutrient removal: ensuring correct sludge age, ammonia derived DO control, separate treatment of reject sludge water for N-removal<br>Mixers: high yield equipment, combined mixing with pumping and/or aeration<br>UV treatment: enhanced inflow quality, dosing rate variation with effluent quality |
| WWTP solid phase | Sludge thickening: low energy equipment (e.g. belts)<br>Sludge end treatment: maximum dewatering to reduce drying energy demand<br>Maximised digestion by increased primary sludge feed, sludge pretreatment, high yield gas motor and/or operational improvement (mixing, temperature) |
| Extensive treatment solutions | Constructed wetlands<br>Land treatment<br>Overland flow |

*Table 2 - Examples of energy production (heat and power generation) in wastewater treatment systems (adapted from Frinjs et al., 2011).*

| INFRASTRUCTURE | ENERGY PRODUCTION (HEAT AND POWER GENERATION) |
|---|---|
| WWTP solid phase | Biogas combined heat and power: process optimisation, co-digestion and enhanced<br>Biogas conversion and use (e.g. green gas) |
| Decentralized | Heat recovery from wastewater at households or from the sewer system<br>Production, co-digestion e.g. with organic kitchen waste.<br>Source-separated sanitation (nutrient recovery combined with heat and power generation). |

### 3.3.4. Asset managment

The asset management main purpose can be summarized as the use of frameworks to design, develop and implement actions to ensure that assets are designed, managed and operated in a sustainable and compliant manner. Most of the advanced asset management techniques are risk-based approaches that measure and forecast asset performance in terms of the ability to operate safely and provide the levels of service to customers and stakeholders. Within these approaches we may say that asset management is already worried with future transition for a more sustainable sector. However, in real world, UWC infrastructures often require long-term commitments that usualy make asset management limited to an economic sustainability perspective of optimizing the use of existent assets instead of a transitional view to a different paradigm of global sustainability.

There are some examples of asset management guidelines and frameworks for adaptation and mitigation to climate changes (MWH, 2007) or specific for asset resilience to flood hazards (Halcrow, 2008).

The MWH (2007) study does not suggest a new way of practicing asset management, nor seeks to repeat or modify the approach of individual water companies. Instead it aims to assist asset planners to incorporate the latest information on climate change impacts, possible adaptation response options, and investment selection criteria that can take account of climate change. The main objectives were to address a number of strategic questions, like:

- Examine what strategic, design, planning, operational or other adaptation options are available, and what timescales are appropriate; assess these, and propose a consistent approach;
- Consider which climate change scenarios, assumptions and data should be used, including the range of uncertainty;

- Suggest a decision-making framework with which to evaluate alternatives and determine a preferred adaptation strategy;
- Engage with regulators and other key stakeholders to explain this Climate Change Adaptation Approach for their normal asset management procedures and to inform an appropriate understanding from economic regulators for the next set of price reviews.

The analytical framework for Asset Resilience to Flood Hazards, developed in behalf of Ofwat (Halcrow, 2008) is a free acess interactive document that provides guidance to water companies for quantifying and managing the future risks to service caused by flood damage to their assets. It includes a summary of current industry practice for assessing asset resilience to flooding and guidelines on assessment of flood hazards, asset vulnerability and consequences of asset failure.

At present times, risk management has a high maturity level. In a conceptual point of view, it is a well-known subject, properly supported by existent standards and with several applications in many activity areas such as roads, health care infrastructures and water sector (Monteiro and Alegre, 2007). In the bibliography there are a lot of references to real case applications and approaches to risk management in water and wastewater (e.g., Calgary, in Alberta, Canada; Hobart Water, in Tasmania, Australia; Hunter Water, Australia; South East Water, United Kingdom; Japanese water utilities, about sismic risk) (Monteiro and Alegre, 2007). Given the maturity already achieved at the conceptual level, it seems more relevant to perform a systematization of the more usual and relevant risks in the area of infrastructure asset management and present recommendations for potential mitigation actions. This systematization should be able to assure a proficient articulation with performance, cost and risk.

In light of the asset management software review conducted by Halfawy et al. (2006), some directions for future research can be identified. Of particular interest is the development of methods and tools for long-term renewal planning of infrastructure assets. The vast majority of the existing softwares focus primarily on supporting the operational day-to-day management activities, and a small number of software tools implement support for long-term renewal planning, but only to a limited extent.

Also, many fundamental asset management functions, such as performance modelling, and maintenance prioritization, important for decision support tools, are not supported by most of the applications. Part of this scarcity can be attributed to the complexity of the long-term planning problem, and the lack of a clear and systematic approach to tackle this problem.

Asset management systems typically support the management of different classes of municipal assets (e.g. roads, water, and sewer networks), with little or no consideration to their inter-dependencies. This lack of integration of asset management activities has created significant inefficiencies in maintenance coordination and asset planning. Optimally, renewal plans for assets at a particular site should be coordinated to span multiple infrastructure assets as much as possible, thus minimizing the disruption, cost, and risks associated with maintenance operations. Integrated asset management is becoming a critical area that future systems will need to support. Including climate changes and new urban design trends for green cities will increase interdependence complexities.

In terms of pathways to a more sustainable UWCS the main conclusion is that water and wastewater assets are usualy long term assets and the design of existing infrastructures was developed under a vision for the future that sometimes is different from today's view. It is possible to have a more rapid transition for implementing a new system according to a sustainable vision in a region with no service at all, rather than reformulating an existent system being obliged to put out of service some usefull and valuable existent assets. Most of the times, it is economically unsustainable to change infrastructures forgeting the assets values we have at the present. This means that transition to a more sustainable future has different pathways and is conditioned from present assets value and present *status quo*.

# 4. CONCLUDING REMARKS

This empirical review was by no means exhaustive. In terms of governance issues, there is a large amount of literature that explores the policy and regulation, financial incentives, and service organisations within the water sector. The purpose of the review in this area was to look specifically at the application of resilience and transitions ideas, and in this context the literature is still somewhat limited. Furthermore, as previously mentioned, the nature of these ideas makes it rather impractical to draw out prescriptive ‘best practices’ that suit all contexts. Above all, these perspectives advocate the need for management measures that ‘fit’ with their social and ecological contexts, and reject a ‘one size fits all’ approach.

In what concerns technical issues, the review performed aimed at presenting how technologies and asset managment strategies can help to build a system's resilience and facilitate the transitioning process. For that purpose, references related to climate change were the most identified, although literature also examines the need to adapt to uncertainty and changing conditions, even in the absence of climate change. It has to be noted that infrastructures that support the UWCS are physical entities upon which several factors act and produce an effect - a "water service" - and determine the overall performance of the system. The need to build resilient systems in order to achieve sustainability must take into account all of the systems components, through a holistic and integrated view. However, there are some potential limits to technology as an adaptation response. Although some adaptations may be technologically possible, they may not be economically feasible or culturally desirable. Adaptations that are effective in one location may be ineffective in other places, or create new vulnerabilities. Nevertheless, in general, the presence of different types of infrastructures can enable resilience at system level and contribute to an adaptation to distinct pressures the system may face. In fact, having alternative water supply sources, increased storage capacity and access to remote sources for contingency use may not seem to be needed for regular exploitation but might significantly increase the resilience in terms of water supply in critical situations. In terms of wastewater drainage and treatment, the use of Stormwater BMP, decentralized solutions and availability of different treatment technologies may also increase the response capacity and turn the system more resilient to assure adequate service levels.

From the examination of grey literature, the overall conclusion is that ideas of resilience and transitions have little evident presence in the UK water sector. Some reports do highlight the need for more resilient infrastructure, but these portrayals are more in keeping with the concept of ‘engineering resilience’ – i.e. capacity for shock absorbance. For instance, the UK government’s strategy ‘Future Water’ (DEFRA, 2008) equates infrastructure resilience with emergency preparedness, and particularly the ability to deal with flooding emergencies. Similarly, the government’s more recent strategy for ‘Climate Resilient Infrastructure’ (DEFRA, 2011) portrays resilience as the ability to withstand future impacts from climate change. The latter strategy does acknowledge that some uncertainty is inevitable, and also argues that resilience means ‘increased flexibility to cope with uncertainty without massive failure and economic cost’. This is more closely aligned with the academic understanding of resilience discussed earlier. However, this understanding is still restricted to physical assets

– there is no discussion of system-wide capacity for innovation, experimentation and learning.

Additionally, there are opportunities to examine the feasibility of resilience and transitions approaches in greater detail, and in a wider range of contexts. While it is difficult to draw out concrete best practices, the literature does appear to coalesce around a number of general principles at the heart of these ideas. Approaches rooted in resilience and transitions perspectives are ones that:

1) *Destabilise the status quo* – In order for a full regime shift to occur, there must be windows of opportunity in the existing regime, which allow radical thinking and innovative measures to take hold. These windows may emerge on their own, but they might also be created through formal, centralised efforts to destabilise the status quo (as with the Dutch transitions policy).
2) *Create linkages* – Drawing in wide range of actors, in order to build bridges between different perspectives and 'ways of knowing', is a central feature of resilience and transitions approaches. This is thought to facilitate innovation and creativity, provided that such interactions do not become 'hijacked' by those with interests in maintaining the status quo (as some argue may have happened in the Dutch energy sector). Furthermore, it is important to create linkages between localised innovations (where they arise), in order to draw together and disseminate the lessons learned from those experiences.
3) *Encourage experimentation and support learning* – These approaches treat management and technological options as experiments, and encourage exploration of the widest possible range of experiments, so that the system as a whole can 'learn by doing' and avoid 'lock in' to particular pathways.
4) *Instil flexibility* – This is arguably the aspect that is most difficult to achieve. The most lauded examples so far are the schemes that allow water management systems to rapidly and proactively adjust their configurations to meet changing conditions. In the case of CALFED, this flexibility was achieved through trading water allocations, and through non-linear planning methods. Whether or not this level of flexibility can be achieved in other aspects of urban water services, such as infrastructure planning, is still very much an open question. In fact, in technological terms this flexibility is usualy obtained through redundancies and/or decentralized options with less scale effect, leading to more expensive solutions.

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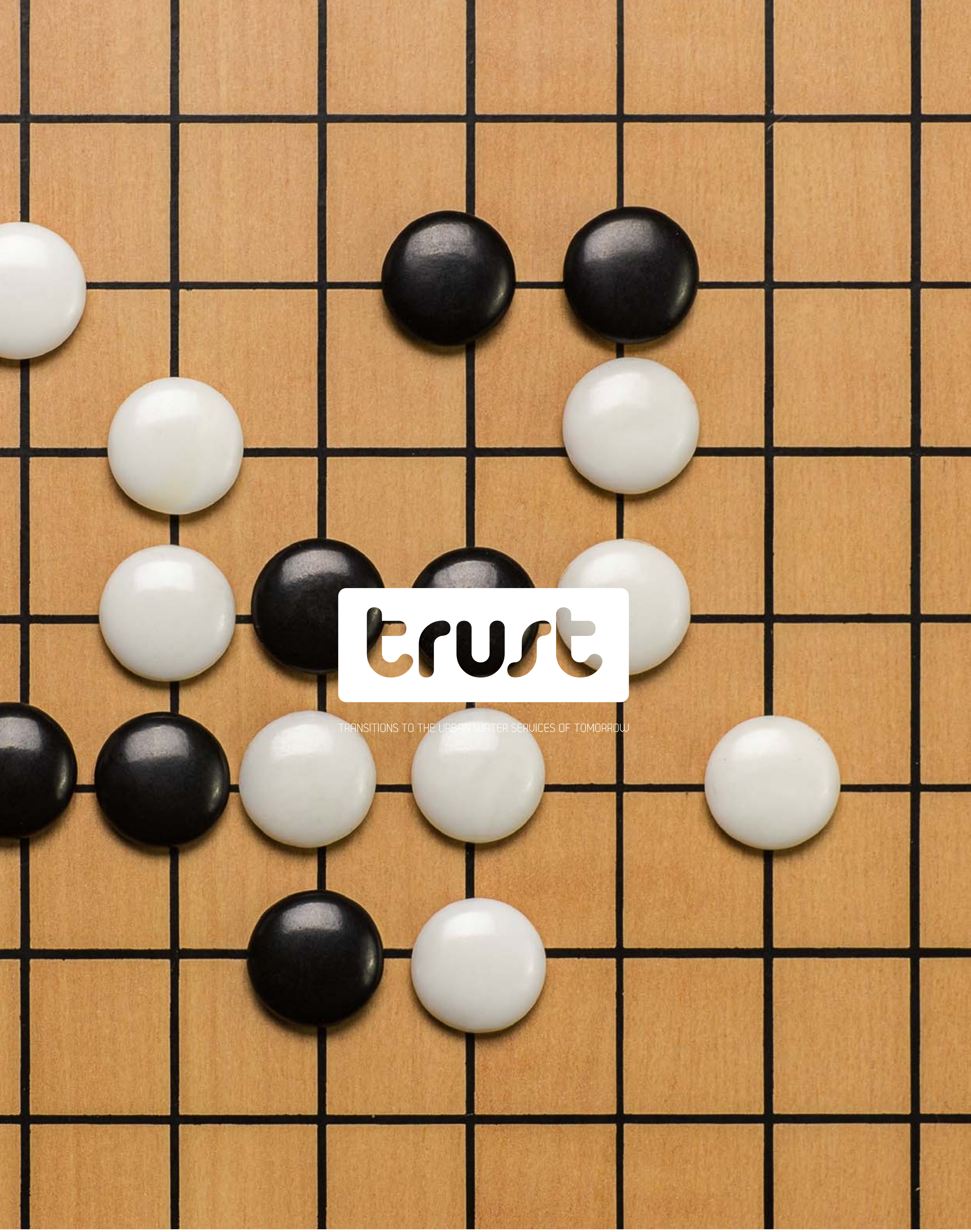

Review on flexible UWCS and transitional pathways

**D 12.1b**

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