Reliability, resilience and sustainability: Can we have it all?

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Abstract
The future reliability, resilience and sustainability of a number of catchment-scale drainage strategies (including green and grey alternatives for the management of stormwater and wastewater) is investigated in an integrated urban drainage case. Reliability, resilience and sustainability indexes are defined by aggregating different performance metrics (flooding, water quality, CSOs, etc.) based on the concept of regret. The results indicate that reliability and resilience are necessary but not sufficient conditions for sustainability, highlighting the role of green infrastructure alternatives and multi-concept srategies as opposed to large grey infrastructure schemes.

Keywords
future uncertainties, integrated urban drainage modelling, performance indicators, reliability, resilience, sustainability.

BACKGROUND AND RELEVANCE

Emerging threats affecting urban areas now and in the future may significantly contribute to the deterioration of the level of service delivered by critical infrastructure, such as urban drainage systems. Climate change, population growth, urbanisation, and other threats could be particularly damaging when simultaneously acting upon these systems. In addition to this, the uncertain nature of these hazards and the unknown magnitude and extent of their impacts over the long-term may question the robustness of conventional and alternative solutions to future changes (Urich and Rauch, 2014).

Under these circumstances, urban drainage infrastructure may be required to undergo adaptive improvements in order to become less vulnerable to potential future conditions, whether these are typical or extraordinary (Ferguson et al., 2013). Indeed, it is expected that urban drainage systems are reliable, able to minimise failure and deliver a satisfactory level of service most of the time, while behaving resiliently to reduce the damage when failure eventually happens (Butler et al., 2014). At the same time, reliable and resilient systems should also pursuit sustainability in the long-term; that is, to comply with operational objectives while not compromising economic, environmental and social goals in the future. In this sense, drainage strategies that provide a high level of technical performance (i.e. reliable and resilient strategies) may not necessarily be financially viable, environmentally balanced (e.g. protecting the aquatic environment at the expense of other environmental issues), or socially equitable.

Understanding the relationship between these operational (reliability and resilience) and strategic (sustainability) goals becomes thus paramount to devise drainage strategies likely to be successful now and in the future. However, there currently exists limited knowledge regarding the extent and qualities of such relationships, and while it seems reasonable to assume that reliability and resilience are necessary conditions for sustainability, it is very challenging to ensure that these are maintained over time and changing conditions.

MATERIALS AND METHODS

The present study approaches the problem of understanding these relationships from a performance point of view, aggregating a range of indicators into reliability, resilience and sustainability indexes (see Table 1). These indexes were evaluated in a case study facing a range of uncertain changes in the future (i.e. climate change, population growth, urban creep, misconnected sewers, groundwater infiltration, changing perceptions), represented in four scenarios.

Table 1: An example of category indicators used to define reliability, resilience and sustainability indexes.

Category	Reliability index	Resilience index	Sustainability index
Sewer Flooding	Flood frequency (annual events)	Flood volume (m^3) Flood duration (hours)	Affected properties Material damage (£)
River DO	Annual events <4 mg/l	Annual low (mg/l) Duration (hours)	Impact to aquatic resources [6 h minimum (mg/l)]
River AMM	Annual events >4 mg/l	Annual high (mg/l) Duration (hours)	Impact to aquatic resources [99%ile (mg/l)]
CSOs	Frequency of spills (annual events)	Annual spill (m^3) Duration of spills (hours)	Aesthetic and health impact of spills
River Flooding	Flood frequency (annual events)	Flood volume (m^3) Flood duration (hours)	Affected properties Material damage (£)
Energy Use	-	-	Operational tCO_2
Cost	-	-	Whole-life costs (£)
Acceptability	-	-	High-med-low

A comprehensive integrated model (Butler et al., 2008), comprising the main elements of the urban wastewater system (i.e. sub-catchments, sewer network, treatment plant and receiving watercourse), was employed to assess the impact of future scenarios on performance indicators and, subsequently, on aggregated indexes. The concept of regret (Lempert et al., 2006; Savage, 1954) was introduced as a measure of the relative failure of each alternative option in delivering reliable, resilient or sustainable wastewater services within each performance category.

The integrated modelling framework consisted of the software platform SIMBA 6.0 (Ifak, 2007) and the hydrodynamic sewer model SWMM 5.0, both coupled to model the integrated urban wastewater system (including catchment, sewer network, wastewater treatment plant, and river models) during one year of extended period simulation. This permitted detailed model representation of hydrologic and quality processes in the catchment (rainfall-runoff generation), sewer hydraulics, physical and biochemical treatment processes, as well as hydrologic and water quality processes taking place in watercourses.

Several alternative strategies (mono-concept solutions) and combinations of alternatives (multi-concept solutions), aiming at the improvement of stormwater and wastewater management in the case study, were similarly tested for reliability, resilience and sustainability under each future scenario. Among others, decentralised source control techniques (e.g. raingardens and bioretention planters) and centralised conventional schemes (e.g. pipe rehabilitation and storage).

RESULTS AND DISCUSSION

- The results obtained suggest that the qualities of reliability and resilience are both positively correlated to that of sustainability; however, these alone are not sufficient to ensure sustainability. Higher levels of reliability were generally found to relate to higher resilience.

- In particular, large grey infrastructure schemes (CST in Figure 1), which resulted in high reliability across scenarios (i.e. low regret scores in Figure 1), did not perform equally highly in terms of resilience and sustainability (i.e. high regret scores).

- Instead, decentralised source control alternatives, such as roof disconnection using raingardens (SCR) or a combination of decentralised and centralised strategies (H4; raingardens, sewer separation and on-site wastewater treatment), provided a balanced performance between reliability, resilience and sustainability regardless of future conditions.

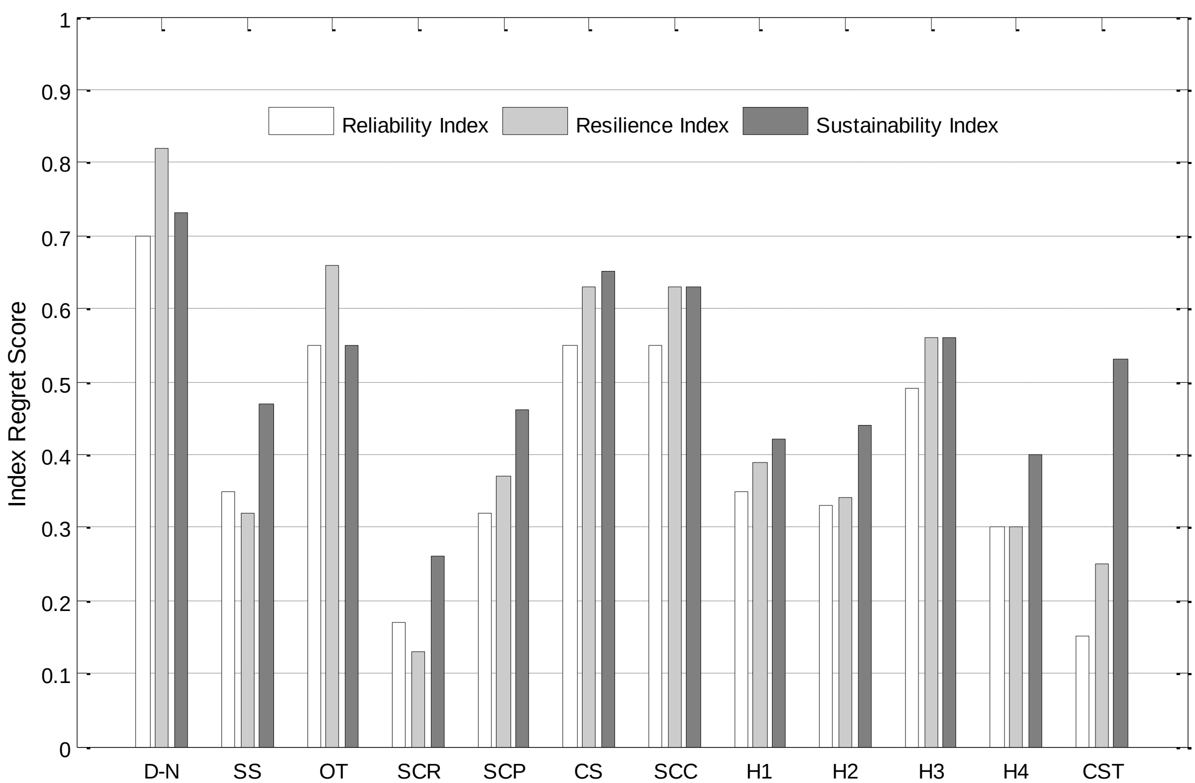

Figure 1: Mean reliability, resilience and sustainability indexes (calculated from four future scenarios) obtained for a number of drainage strategies applied to the case study.

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