Supporting Information

Strategic Planning of the Integrated Urban Wastewater System using Adaptation Pathway Maps

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This document consists of 37 pages, 25 Tables and 30 Figures.

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## S1. The terms defined or used in this paper

| Terms                  | Definition/description                                                                                                                                                                                                 | Reference                        |
|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| Adaptation            | Adaptation here refers to carrying out improvements on the drainage infrastructure, i.e. the engineering assets that normally define this type of systems.                                                                 | Butler et al. (2017)               |
| Adaptation strategies | Adaptation interventions considered in this study. These may be conventional grey infrastructure (i.e. sewer pipes, pumps, storage tanks and treatment facilities) as well as alternative green infrastructure (i.e. SuDS, BMPs). | This study                        |
| Adaptation thresholds | 1. The points where changing conditions oblige a normally stable state of a system into another state or facilitate adaptation of the system (called also tipping points) | van Veelen et al. (2015)          |
|                       | 2. The points where the magnitude of changes (e.g. due to climate change) is such that the current strategy will no longer be able to meet objectives under different future scenarios (also called tipping points) | Kwadijk et al. (2010) and Renaud et al. (2013) |
|                       | 3. The points at which threats exceed the system’s ability to respond and recover (called recovery points)                                                                                                          | van Veelen et al. (2015)          |
|                       | 4. The physical boundary conditions where acceptable technical, environmental, societal or economic standards may be compromised, requiring implementation of new actions to meet the specified objective (called also tipping points) | Manocha and Babovic, (2017)       |
|                       | 5. An adaptation limit as a point at which an action is no longer likely to be able to provide cost effective risk reduction, subject to social and environmental considerations (called also adaptation limit) | Kingsborough et al. (2016)        |
|                       | 6. The condition (or conditions) under which the current management strategy is no longer able to meet the clearly defined objective (or objectives) across a timeline; at this point, alternative adaptation strategies should be considered. Adaptation thresholds are used to evaluate the adaption domain size | This study                        |
| Adaptation domain     | A set of possible future states or transient scenarios in which an adaptation strategy is compliance to the adaptation threshold or thresholds. The domain size of a strategy is identified using adaptation thresholds. The domain size is evaluated in two complementary ways: (i) the number of complying epochs across the scenarios and (ii) whether or not the pathways are uninterrupted (i.e. compliant) or interrupted (i.e. non-compliant) to one or more adaptation thresholds across the entire timeline | This study                        |
| Adaptation pathways   | 1. Alternative possible trajectories for knowledge, intervention and change, which prioritize different goals, values and functions                                                                                       | Leach et al. (2010)               |
|                       | 2. An analytical and foresight approach for exploring and sequencing a set of possible strategies along the planning timeline                                                                                           | Haasnoot et al. (2013)            |
|                       | 3. An approach that explores alternative sequences of investment decisions to achieve objectives over time in the context of uncertain future developments and environmental changes | Haasnoot et al. (2019)            |
|                       | 4. An approach that provides a visual representation of the potential sequencing and type of actions that may be implemented in the future.                                                                         | (Kingsborough et al. 2016)        |
|                       | 5. A path (or series of paths) in which a strategy (or a combination of strategies) is compliant with the adaptation threshold(s).                                                                                | This study                        |
### Table S1 (Part 2): The terms on adaptation and adaptation pathways defined and/or used in this study

| Terms                        | Definition/description                                                                                                                                                                                                 | Reference                  |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| **Adaptation pathway map**   | This identifies possible pathways (or possible domain in different future states) along the planning timelines with respect to different adaptation thresholds                                                                 | This study                  |
| **Sell-by-date**             | 1. The time when a strategy violates an adaptation threshold                                                                                                                                                           | Haasnoot et al. (2013)      |
|                              | 2. The period when a strategy option is expected to require adaptation or additional measures to be put in place due to an interruption of its satisfactory pathway of transient scenarios                                         | van Veelen et al. (2015)    |
|                              | 3. The time epoch(s) when a strategy no longer achieves a set objective, when the compliant pathway of that specific strategy is interrupted                                                                            | This study                  |
| **Epochs or transient scenarios** | Future scenarios at time intervals of every 5-years                                                                                                                                                                     | This study                  |
S2. Parameters used to distinguish different future scenarios from each other

The future scenarios differ from one another with respect to nine parameters (variables) indicative of various IUWWS uncertain conditions (Casal-Campos et al., 2018, 2015):

(1) Misconnections (L/s): the amount of misconnected foul sewers discharging into surface sewers was assumed to be related to existing regulations enforcing the identification of such misconnections as well as to the level of maintenance regimes required to undertake remedial reconnection work.

(2) Urban creep (ha): The level of urban creep happening in a scenario is a function of the level of regulations limiting the amount of uncontrolled re-surfacing of permeable areas as well as of the public willingness to implement decentralized surface water management measures that serve those new contributing areas. If both aspects were strong under a given scenario, the level of urban creep was therefore very low (Casal-Campos et al., 2015).

(3) Water use (L/head/day): Positive attitudes towards the decentralization of water management responsibilities had an influence in reducing domestic water use (e.g. facilitate demand-side measures), along with the role of regulations and water efficient technologies.

(4) Infiltration (L/s): infiltration of groundwater into sewers is assumed to be a consequence of both low sewer maintenance regimes and the unavailability of technological solutions to provide cost-effective maintenance.

(5) Siltation: As with infiltration, the degree of siltation is determined by the level of maintenance in the sewer infrastructure and the availability of technologies that facilitate such maintenance.

(6) Population (inhabitants): population growth as an external threat is assumed to be independent of the internal uncertainties, since it is outside of the control of the IUWWS management. This parameter is defined according to the socio-economic conditions described in Casal-Campos et al. (Casal-Campos et al., 2015).

(7) CC precipitation uplift (%): the effect of climate change in rainfall intensity was considered independent of scenario conditions, since it was assumed that the sensitivity of precipitation predictions to different scenarios up to the year 2050 is modest, according to UK guidance (Kirtman et al., 2013).
(8) Impervious area in new developments (ha): Permeability changes were represented by the rate of urban creep occurring in the baseline catchment (i.e. loss of permeable area to impervious area in the original catchment) and by the increase in impervious area occurring as a consequence of urbanization (i.e. new developments) (Casal-Campos et al., 2015).

(9) Acceptability preference: acceptability of interventions under each scenario is assessed in terms of the preference for either centralized or decentralized options). These parameters were mostly linked to variations in catchment permeability and to the changes in sewer inflows, which could deteriorate system capacity in the future (Casal Campos, 2016; Casal-Campos et al., 2018).

Table S2: Parameter estimates affecting case conditions under each future scenario (adapted from Casal-Campos et al., 2018, 2015)

| Parameter                        | Baseline | Markets | Innovation | Austerity | Lifestyles |
|----------------------------------|----------|---------|------------|-----------|------------|
| Misconnections (L/s)             | 0        | 7.8     | 0.9        | 4.1       | 1.7        |
| Urban creep (ha)                 | 0        | 87.7    | 58.4       | 70.1      | 29.2       |
| Water use (L/head/day)           | 155      | 165     | 125        | 140       | 110        |
| Infiltration¹ (L/s)              | 52.4     | 163.7   | 40.5       | 200.1     | 135.5      |
| Siltation²                       | 0.97     | 0.92    | 1          | 0.84      | 0.92       |
| Population (inhabitants)         | 181,000  | 262,450 | 244,350    | 217,200   | 226,250    |
| CC precipitation uplift (%)      | 0        | 10      | 10         | 10        | 10         |
| Impervious area in new developments (ha) | 0       | 290.0   | 226.0      | 129.0     | 161.0      |
| Acceptability preference³        | C        | C       | C/D        | D         | D          |

1. It refers to infiltration of groundwater into the sewer system.
2. The effect of siltation, which represented system capacity loss in sewer pipes due to deposited sediment, was modelled as the corresponding reduction in pipe diameter under each scenario (corresponding to full-pipe area reduction); 1: no reduction, 0: full reduction.
3. The acceptability of interventions under each scenario is assessed in terms of the preference for either Centralized (C) or Decentralized (D) options. The Innovation scenario shows a mixed preference for centralized interventions, where decentralization is also promoted.
### S3. Performance objectives and indicators

Table S3: Performance objectives and indicators used to define impacts and consequences (adapted from Casal-Campos et al. (2018))

| Objectives | Reliability Indicators | Resilience Indicators | Sustainability Indicators |
|------------|------------------------|-----------------------|---------------------------|
| Sewer Flowing | % time free of flood | Summation of duration-weighted flood volumes $[m^3]$ | Total flood volume $[m^3]$ |
| River DO | % time $DO > 4 \text{ mg/l}$ | Summation of duration-weighted DO minima $[\text{mg/l}]$ | 6-hour minimum dissolved oxygen $[\text{mg/l}]$ |
| River AMM | % time $AMM < 4 \text{ mg/l}$ | Summation of duration-weighted AMM minima $[\text{mg/l}]$ | 99 percentile total ammonia $[\text{mg/l}]$ |
| CSOs | % time not spilling | Summation of duration-weighted spill volumes $[m^3]$ | Total spill volume $[m^3]$ |
| River Flooding | % time free of flood | Summation of duration-weighted flood volumes $[m^3]$ | Total flood volume $[m^3]$ |
| GHG Emissions | - | - | Total operational emissions from pumping & treatment $[tCO_2]$ |
| Costs | - | - | PV of whole-life costs $[\text{£}]$ |
| Acceptability | - | - | Acceptability level of strategies $[\text{Low accept (L)} = 1; \text{Medium accept (M)} = 2; \text{High accept (H)} = 3]$ |

**DO:** Dissolved Oxygen; **AMM:** River Total Ammonia; **GHG:** Green House Gas
S4. Design considerations for hybrid strategies

S4.1 Attenuation volume of SCR and CST

Attenuation capacity of SCR (rain gardens):

Area removed is 34% of total area:\(^\text{A}\):

\[ 758.9 \times 0.34 = 258 \text{ ha} \]

Assuming 20 mm of attenuation storage for rain gardens:

\[ 258 \text{ ha} \times 10,000 \frac{\text{m}^2}{\text{ha}} \times 20 \times 10^{-3} \text{ m} = 51,600 \text{ m}^3 \]

This is comparable to the storage volume proposed for the CST strategy (50,000 m³).

S4.2 Design of hybrid strategies

50% of SCR strategy removes 17% of total area: \( 758.9 \times 0.17 = 129 \text{ ha} \)

Annual rainfall in 2050: 683.4 mm

Annual volume managed by 50% of SCR:

\[ 129 \text{ ha} \times 10,000 \frac{\text{m}^2}{\text{ha}} \times 683.4 \times 10^{-3} \text{ m} = 881,586 \text{ m}^3/\text{year} \]

Fraction of OT (on-site wastewater treatment) to manage an equivalent volume:

Average population increase in 2050 (mean growth across scenarios): 56,563\(^\text{B}\)

Average population affected by OT in 2050: 28,282

Average water use in 2050: 135 L/h/day

Average wastewater volume managed by OT: 28,282 \times 135 \times 365 = 1,393,596 \text{ m}^3/\text{year}

Fraction of OT required for managing the volume of 50% SCR [881,586 m³/year]:

\[ \frac{881,586}{1,393,596} = 0.63 \text{ (63% of OT)} \]

Fraction of SS to manage an equivalent volume:

Average separate area managed by SS across scenarios in 2050: 323 ha

Annual volume managed on average by SS:

\[ \text{typical value in UK terraced residential developments (Ward et al., 2012)} \]

\[ \text{Calculated in Casal-Campos et al. (2015)} \]
\[
323 \text{ ha} \times 10,000 \frac{\text{m}^2}{\text{ha}} \times 683.4 \times 10^{-3} \text{ m} = 2,206,382 \text{ m}^3/\text{year}
\]

Fraction of SS required for managing the volume of 50% SCR [881,586 m$^3$/year]:

\[
\frac{881,586}{2,206,382} = 0.4 \text{ (40% of SS)}
\]
S5. Results on different domains for single adaptation threshold

S5.1 Reliability domains for single adaptation threshold

| Scenarios | Strategies | Adaptation Threshold |
|-----------|------------|----------------------|
| M: Markets; A: Austerity; I: Innovation; L: Lifestyles | D-N: do-nothing; SCC: permeable pavement; SCR: bio-retention planters; CSOs: sewer separation; CST: improved sewer capacity & storage tank; CS: improved sewer capacity; OT: on-site treatment; H1: SCR+OT; H2: SCR+SS; H3: SS+OT; H4: SCR+CS | Single adaptation threshold |

Fig. S1: Reliability domains for the sewer flooding adaptation threshold. The compliant domain (coloured tiles) ranges from low (green) to high regret (red). Non-compliant and full-regret tiles are shown in grey.

Fig. S2: Reliability domains for the CSOs adaptation threshold.
Fig. S3: Reliability domains for the river flooding adaptation threshold.

S5.2 Resilience domains for single adaptation threshold

Fig. S4: Resilience domains for the river flooding adaptation threshold.
S5.3 Sustainability domains for single adaptation threshold

Fig. S5: Sustainability domains for the sewer flooding adaptation threshold.

Fig. S6: Sustainability domains for the CSOs adaptation threshold.

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S5.4 Reliability-Resilience domains for single adaptation threshold

Fig. S7: Sustainability domains for the river flooding adaptation threshold.

Fig. S8: Reliability and resilience domains for the sewer flooding adaptation threshold.
Fig. S9: Reliability and resilience domains for the CSOs adaptation threshold.

Fig. S10: Reliability and resilience domains for the river flooding adaptation threshold.
S5.5 Reliability-Sustainability domains for single adaptation threshold

Fig. S11: Reliability and sustainability domains for the sewer flooding adaptation threshold.

Fig. S12: Reliability and sustainability domains for the CSOs adaptation threshold.
Fig. S13: Reliability and sustainability domains for the river flooding adaptation threshold.

S5.6 Resilience-Sustainability domains for single adaptation threshold

Fig. S14: Resilience and sustainability domains for the sewer flooding adaptation threshold.

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**Fig. S16:** Resilience and sustainability domains for the river flooding adaptation threshold.
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Fig. S17: Reliability, resilience and sustainability domains for the sewer flooding adaptation threshold.

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S6. Results on different domains for multiple adaptation thresholds

S6.1 Reliability domains for multiple adaptation thresholds

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Fig. S21: Reliability domains for the sewer flooding, CSO and river flooding adaptation thresholds.

S6.2 Resilience domains for multiple adaptation thresholds

Fig. S22: Resilience domains for the sewer flooding and CSO adaptation thresholds.
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S6.3 Sustainability domains for multiple adaptation thresholds

Fig. S24: Sustainability domains for the sewer flooding and CSO adaptation thresholds.
S6.4 Reliability-Resilience domains for multiple adaptation thresholds

Fig. S25: Sustainability domains for the sewer flooding, CSO and river flooding adaptation thresholds.

Fig. S26: Reliability and resilience domains for the sewer flooding and CSO adaptation thresholds.
Fig. S27: Reliability and resilience domains for CSO and sewer and river flooding adaptation thresholds.

S6.5 Reliability-Sustainability domains for multiple adaptation thresholds

Fig. S28: Reliability and sustainability domains for the sewer flooding and CSO adaptation thresholds.
S6.6 Resilience-Sustainability domains for three adaptation thresholds

Fig. S29: Reliability and sustainability domains for sewer flooding, CSO and river flooding thresholds.

Fig. S30: Resilient and sustainable domains for sewer flooding, CSO and river flooding adaptation thresholds.
S7. Detailed results on adaptation compliancy of the strategies (evaluation of the domain size)

S7.1 Results on compliancy of the strategies with respect to multiple adaptation thresholds and multiple domains (resilience-sustainability)

Table S4: Compliancy of the strategies with respect to the domains of resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2020

| Scenarios | Markets 2020 | Innovation 2020 | Austerity 2020 | Lifestyles 2020 |
|-----------|--------------|-----------------|---------------|-----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN        | NC           | NC              | NC            | NC              | NC              | NC              |
| SCC       | NC           | NC              | NC            | NC              | NC              | NC              |
| SCR       | NC           | NC              | C             | NC              | NC              | C               |
| SCP       | NC           | NC              | NC            | NC              | NC              | NC              |
| OT        | NC           | NC              | NC            | NC              | NC              | NC              |
| SS        | C            | NC              | C             | NC              | C               | C               |
| CST       | C            | NC              | C             | NC              | C               | C               |
| CS        | C            | NC              | C             | NC              | C               | C               |
| H1        | NC           | NC              | NC            | NC              | NC              | NC              |
| H2        | NC           | NC              | C             | NC              | C               | C               |
| H3        | NC           | NC              | NC            | NC              | NC              | NC              |
| H4        | C            | NC              | C             | C               | C               | C               |

* C: Compliant
** NC: Non-Compliant (in grey colour)

Table S5: Compliancy of the strategies with respect to the domains of resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2025

| Scenarios | Markets 2025 | Innovation 2025 | Austerity 2025 | Lifestyles 2025 |
|-----------|--------------|-----------------|---------------|-----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN        | NC           | NC              | NC            | NC              | NC              | NC              |
| SCC       | NC           | NC              | NC            | NC              | NC              | NC              |
| SCR       | C            | NC              | C             | C               | C               | C               |
| SCP       | NC           | NC              | C             | NC              | NC              | C               |
| OT        | NC           | NC              | NC            | NC              | NC              | NC              |
| SS        | C            | NC              | C             | C               | C               | C               |
| CST       | C            | NC              | C             | NC              | C               | C               |
| CS        | NC           | NC              | NC            | NC              | NC              | NC              |
| H1        | NC           | NC              | C             | NC              | C               | C               |
| H2        | NC           | NC              | NC            | NC              | NC              | C               |
| H3        | NC           | NC              | C             | NC              | NC              | NC              |
| H4        | C            | NC              | C             | C               | C               | C               |

* C: Compliant
** NC: Non-Compliant (in grey colour)
Table S6: Compliancy of the strategies with respect to the domains of resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2030

| Scenarios | Markets 2030 | Innovation 2030 | Austerity 2030 | Lifestyles 2030 |
|-----------|--------------|-----------------|----------------|-----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN        | NC           | NC              | NC             | NC              | NC              | NC |
| SCC       | NC           | NC              | NC             | NC              | NC              | NC |
| SCR       | NC           | NC              | C              | NC              | NC              | C  |
| SCP       | NC           | NC              | NC             | NC              | NC              | NC |
| OT        | NC           | NC              | NC             | NC              | NC              | NC |
| SS        | NC           | NC              | C              | NC              | NC              | NC |
| CST       | NC           | NC              | C              | NC              | NC              | C  |
| CS        | NC           | NC              | NC             | NC              | NC              | NC |
| H1        | NC           | NC              | NC             | NC              | NC              | NC |
| H2        | NC           | NC              | C              | NC              | NC              | C  |
| H3        | NC           | NC              | C              | NC              | NC              | NC |
| H4        | NC           | NC              | C              | NC              | NC              | C  |

* * C: Compliant
** NC: Non-Compliant (in grey colour)

Table S7: Compliancy of the strategies with respect to the domains of resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2035

| Scenarios | Markets 2035 | Innovation 2035 | Austerity 2035 | Lifestyles 2035 |
|-----------|--------------|-----------------|----------------|-----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN        | NC           | NC              | NC             | NC              | NC              | NC |
| SCC       | NC           | NC              | NC             | NC              | NC              | NC |
| SCR       | NC           | NC              | C              | NC              | NC              | C  |
| SCP       | NC           | NC              | C              | NC              | NC              | NC |
| OT        | NC           | NC              | NC             | NC              | NC              | NC |
| SS        | NC           | NC              | C              | NC              | NC              | NC |
| CST       | NC           | NC              | C              | NC              | NC              | NC |
| CS        | NC           | NC              | NC             | NC              | NC              | NC |
| H1        | NC           | NC              | NC             | NC              | NC              | NC |
| H2        | NC           | NC              | C              | NC              | NC              | C  |
| H3        | NC           | NC              | C              | NC              | NC              | C  |
| H4        | NC           | NC              | C              | NC              | NC              | C  |

* * C: Compliant
** NC: Non-Compliant (in grey colour)
Table S8: Compliancy of the strategies with respect to the domains of resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2040

| Scenarios | Markets 2040 | Innovation 2040 | Austerity 2040 | Lifestyles 2040 |
|-----------|--------------|----------------|---------------|----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN        | NC           | NC             | NC            | NC             | NC             | NC             |
| SCC       | NC           | NC             | NC            | NC             | NC             | NC             |
| SCR       | NC           | C              | NC            | C              | NC             | NC             |
| SCP       | NC           | C              | NC            | C              | NC             | NC             |
| OT        | NC           | NC             | NC            | NC             | NC             | NC             |
| SS        | C            | NC             | NC            | C              | NC             | NC             |
| CST       | NC           | C              | NC            | C              | NC             | NC             |
| CS        | NC           | NC             | NC            | NC             | NC             | NC             |
| H1        | NC           | C              | NC            | C              | NC             | NC             |
| H2        | NC           | C              | NC            | C              | NC             | NC             |
| H3        | NC           | NC             | NC            | NC             | NC             | NC             |
| H4        | C            | NC             | C             | C              | NC             | NC             |

* C: Compliant
** NC: Non-Compliant (in grey colour)

Table S9: Compliancy of the strategies with respect to the domains of resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2045

| Scenarios | Markets 2045 | Innovation 2045 | Austerity 2045 | Lifestyles 2045 |
|-----------|--------------|----------------|---------------|----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN        | NC           | NC             | NC            | NC             | NC             | NC             |
| SCC       | NC           | NC             | NC            | NC             | NC             | NC             |
| SCR       | C            | NC             | C             | NC             | C              | NC             |
| SCP       | NC           | NC             | NC            | NC             | NC             | NC             |
| OT        | NC           | NC             | NC            | NC             | NC             | NC             |
| SS        | C            | NC             | NC            | C              | NC             | NC             |
| CST       | NC           | C              | NC            | C              | NC             | NC             |
| CS        | NC           | NC             | NC            | NC             | NC             | NC             |
| H1        | NC           | NC             | NC            | NC             | NC             | NC             |
| H2        | C            | NC             | NC            | C              | NC             | NC             |
| H3        | NC           | NC             | NC            | NC             | NC             | NC             |
| H4        | C            | NC             | C             | C              | NC             | NC             |

* C: Compliant
** NC: Non-Compliant (in grey colour)
Table S10: Compliancy of the strategies with respect to the domains of resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2050

| Scenarios | Markets 2050 | Innovation 2050 | Austerity 2050 | Lifestyles 2050 |
|-----------|--------------|----------------|---------------|-----------------|
| **Objectives** | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN | NC | NC | NC | NC | NC | NC | NC | NC |
| SCC | NC | NC | NC | NC | NC | NC | NC | NC |
| SCR | C | NC | C | NC | C | NC | C | NC |
| SCP | NC | NC | C | NC | NC | NC | C | NC |
| OT | NC | NC | NC | NC | NC | NC | NC | NC |
| SS | C | NC | C | NC | C | NC | C | NC |
| CST | NC | NC | C | NC | C | NC | C | NC |
| CS | NC | NC | NC | NC | NC | NC | NC | NC |
| H1 | NC | NC | C | NC | NC | NC | NC | NC |
| H2 | C | NC | C | NC | C | NC | C | NC |
| H3 | NC | NC | C | NC | NC | NC | C | NC |
| H4 | C | NC | C | NC | C | NC | C | C |

* C: Compliant  
** NC: Non-Compliant (in grey colour)

S7.2 Results on compliancy of the strategies with respect to multiple adaptation thresholds and multiple domains (reliability-resilience-sustainability)

Table S11: Compliancy of the strategies with respect to the domains of reliability-resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2020

| Scenarios | Markets 2020 | Innovation 2050 | Austerity 2050 | Lifestyles 2050 |
|-----------|--------------|----------------|---------------|-----------------|
| **Objectives** | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN | NC | NC | NC | NC | NC | NC | NC | NC |
| SCC | NC | NC | NC | NC | NC | NC | NC | NC |
| SCR | NC | NC | C | C | NC | NC | C | C |
| SCP | NC | NC | C | NC | NC | NC | C | C |
| OT | NC | NC | NC | NC | NC | NC | NC | NC |
| SS | C | NC | C | NC | C | NC | C | C |
| CST | C | NC | C | NC | C | NC | C | C |
| CS | C | NC | C | NC | C | NC | C | C |
| H1 | NC | NC | NC | NC | NC | NC | NC | NC |
| H2 | NC | NC | C | C | NC | NC | C | C |
| H3 | NC | NC | NC | NC | NC | NC | NC | NC |
| H4 | C | NC | C | C | C | C | C | C |

* C: Compliant  
** NC: Non-Compliant (in grey colour)
Table S12: Compliancy of the strategies with respect to the domains of reliability-resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2025

| Scenarios | Markets 2025 | Innovation 2025 | Austerity 2025 | Lifestyles 2025 |
|-----------|--------------|-----------------|----------------|-----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN | NC | NC | NC | NC | NC | NC |
| SCC | NC | NC | NC | NC | NC | NC |
| SCR | C | NC | C | C | C | C |
| SCP | NC | NC | C | C | C | C |
| OT | NC | NC | NC | NC | NC | NC |
| SS | C | NC | C | NC | C | NC |
| CST | NC | NC | C | NC | C | NC |
| CS | NC | NC | C | NC | NC | NC |
| H1 | NC | NC | C | NC | NC | NC |
| H2 | NC | NC | C | NC | NC | C |
| H3 | NC | NC | C | NC | NC | C |
| H4 | C | NC | C | C | C | C |

* C: Compliant
** NC: Non-Compliant (in grey colour)

Table S13: Compliancy of the strategies with respect to the domains of reliability-resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2030

| Scenarios | Markets 2030 | Innovation 2030 | Austerity 2030 | Lifestyles 2030 |
|-----------|--------------|-----------------|----------------|-----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN | NC | NC | NC | NC | NC | NC |
| SCC | NC | NC | NC | NC | NC | NC |
| SCR | NC | NC | C | NC | NC | C |
| SCP | NC | NC | NC | NC | NC | NC |
| OT | NC | NC | C | NC | NC | C |
| SS | NC | NC | C | NC | NC | C |
| CST | NC | NC | C | NC | NC | C |
| CS | NC | NC | C | NC | NC | C |
| H1 | NC | NC | C | NC | NC | C |
| H2 | NC | NC | C | NC | NC | C |
| H3 | NC | NC | C | NC | NC | C |
| H4 | C | NC | C | C | C | C |

* C: Compliant
** NC: Non-Compliant (in grey colour)
Table S14: Compliancy of the strategies with respect to the domains of reliability-resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2035

| Scenarios | Markets 2035 | Innovation 2035 | Austerity 2035 | Lifestyles 2035 |
|-----------|--------------|----------------|---------------|----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN        | NC           | NC             | NC            | NC             | NC             | NC             | NC             |
| SCC       | NC           | NC             | NC            | NC             | NC             | NC             | NC             |
| SCR       | NC           | C              | NC            | NC             | NC             | NC             | C              |
| SCP       | NC           | C              | NC            | NC             | NC             | NC             | C              |
| OT        | NC           | NC             | NC            | NC             | NC             | NC             | C              |
| SS        | NC           | C              | NC            | NC             | NC             | NC             | C              |
| CST       | NC           | NC             | NC            | NC             | NC             | NC             | C              |
| CS        | NC           | NC             | NC            | NC             | NC             | NC             | C              |
| H1        | NC           | NC             | NC            | NC             | NC             | NC             | C              |
| H2        | NC           | NC             | NC            | NC             | NC             | NC             | C              |
| H3        | NC           | NC             | NC            | NC             | NC             | NC             | C              |
| H4        | NC           | C              | NC            | NC             | NC             | NC             | C              |

* C: Compliant
** NC: Non-Compliant (in grey colour)

Table S15: Compliancy of the strategies with respect to the domains of reliability-resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2040

| Scenarios | Markets 2040 | Innovation 2040 | Austerity 2040 | Lifestyles 2040 |
|-----------|--------------|----------------|---------------|----------------|
| Objectives | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding | CSO, Sewer, flooding & river flooding | CSO & Sewer flooding | CSO, Sewer, flooding & river flooding |
| DN        | NC           | NC             | NC            | NC             | NC             | NC             |
| SCC       | NC           | NC             | NC            | NC             | NC             | NC             |
| SCR       | NC           | C              | NC            | NC             | NC             | NC             |
| SCP       | NC           | C              | NC            | NC             | NC             | NC             |
| OT        | NC           | NC             | NC            | NC             | NC             | NC             |
| SS        | NC           | C              | NC            | NC             | NC             | NC             |
| CST       | NC           | NC             | NC            | NC             | NC             | NC             |
| CS        | NC           | NC             | NC            | NC             | NC             | NC             |
| H1        | NC           | NC             | NC            | NC             | NC             | NC             |
| H2        | NC           | NC             | NC            | NC             | NC             | NC             |
| H3        | NC           | NC             | NC            | NC             | NC             | NC             |
| H4        | NC           | C              | NC            | NC             | NC             | NC             |

* C: Compliant
** NC: Non-Compliant (in grey colour)
Table S16: Compliancy of the strategies with respect to the domains of reliability-resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2045

| Strategies | Markets 2045 | Innovation 2045 | Austerity 2045 | Lifestyles 2045 |
|------------|--------------|-----------------|---------------|----------------|
| DN         | NC           | NC              | NC            | NC             |
| SCC        | NC           | NC              | NC            | NC             |
| SCR        | NC           | C               | NC            | C              |
| SCP        | NC           | C               | NC            | C              |
| OT         | NC           | NC              | NC            | C              |
| SS         | NC           | C               | NC            | C              |
| CST        | NC           | NC              | NC            | NC             |
| CS         | NC           | NC              | NC            | NC             |
| H1         | NC           | C               | NC            | C              |
| H2         | NC           | C               | NC            | C              |
| H3         | NC           | C               | NC            | C              |
| H4         | NC           | C               | NC            | C              |

* C: Compliant
** NC: Non-Compliant (in grey colour)

Table S17: Compliancy of the strategies with respect to the domains of reliability-resilience-sustainability and multiple adaptation thresholds in the epoch ending in 2050

| Strategies | Markets 2050 | Innovation 2050 | Austerity 2050 | Lifestyles 2050 |
|------------|--------------|-----------------|---------------|----------------|
| DN         | NC           | NC              | NC            | NC             |
| SCC        | NC           | NC              | NC            | NC             |
| SCR        | NC           | C               | NC            | C              |
| SCP        | NC           | C               | NC            | C              |
| OT         | NC           | NC              | NC            | C              |
| SS         | NC           | NC              | NC            | C              |
| CST        | NC           | NC              | NC            | NC             |
| CS         | NC           | NC              | NC            | NC             |
| H1         | NC           | C               | NC            | C              |
| H2         | NC           | C               | NC            | C              |
| H3         | NC           | C               | NC            | C              |
| H4         | NC           | C               | NC            | C              |

* C: Compliant
** NC: Non-Compliant (in grey colour)
S8. Detailed results on the assessment of strategies by the regret indices

S8.1 Results on regret levels in the multiple domains of resilience-sustainability

Table S18: Resilience-sustainability regret index in the epoch ending in 2020 and 2025

| Strategies | Epoch ending in 2020 | Epoch ending in 2025 |
|------------|----------------------|----------------------|
| DN         | 0.817 0.847 0.735 0.679 1.000 | 1.000 1.000 0.754 1.000 |
| SCC        | 0.719 0.619 0.632 0.531 1.000 | 1.000 1.000 0.653 1.000 |
| SCR        | 0.342 0.273 0.262 0.261 0.306 | 0.289 0.282 0.240 0.240 |
| SCP        | 0.528 0.452 0.464 0.294 1.000 | 0.449 0.452 0.386 0.386 |
| OT         | 0.615 0.744 0.702 0.482 1.000 | 1.000 1.000 0.638 0.611 |
| SS         | 0.513 0.544 0.451 0.406 0.512 | 0.479 0.476 0.436 0.436 |
| CST        | 0.475 0.441 0.374 0.389 0.441 | 0.481 0.399 0.405 0.405 |
| CS         | 0.561 0.592 0.592 0.659 0.756 | 0.766 0.617 0.747 0.747 |
| H1         | 0.474 0.440 0.428 0.331 1.000 | 1.000 1.000 0.414 0.290 |
| H2         | 0.435 0.425 0.356 0.315 0.413 | 0.416 0.368 0.349 0.349 |
| H3         | 0.572 0.576 0.529 0.437 1.000 | 1.000 1.000 0.484 0.389 |
| H4         | 0.265 0.199 0.230 0.293 0.217 | 0.175 0.147 0.255 0.255 |

Table S19: Resilience-sustainability regret index in the epoch ending in 2030 and 2035

| Strategies | Epoch ending in 2030 | Epoch ending in 2035 |
|------------|----------------------|----------------------|
| DN         | 1.000 1.000 1.000 1.000 | 1.000 1.000 1.000 1.000 |
| SCC        | 1.000 1.000 0.814 1.000 | 1.000 1.000 1.000 1.000 |
| SCR        | 1.000 0.616 0.259 0.168 | 0.684 0.235 0.263 0.175 |
| SCP        | 1.000 1.000 0.422 0.345 | 1.000 1.000 0.419 0.320 |
| OT         | 1.000 1.000 1.000 1.000 | 1.000 1.000 1.000 1.000 |
| SS         | 0.768 0.526 0.456 0.407 | 0.459 0.463 0.432 0.394 |
| CST        | 0.604 0.469 0.391 0.387 | 0.601 0.455 0.385 0.376 |
| CS         | 1.000 1.000 0.775 0.752 | 1.000 1.000 0.763 0.750 |
| H1         | 1.000 1.000 0.396 1.000 | 1.000 1.000 0.354 0.285 |
| H2         | 1.000 0.695 0.386 0.304 | 0.716 0.359 0.364 0.301 |
| H3         | 1.000 1.000 0.508 1.000 | 1.000 1.000 0.495 0.721 |
| H4         | 0.540 0.178 0.163 0.216 | 0.529 0.177 0.169 0.195 |
Table S20: Resilience-sustainability regret index in the epoch ending in 2040 and 2045

| Strategies | Epoch ending in 2040 | Epoch ending in 2045 |
|------------|----------------------|----------------------|
| DN         | 1.000                | 1.000                |
|            | 1.000                | 1.000                |
| SCC        | 1.000                | 1.000                |
|            | 0.693                | 0.223                |
| SCR        | 1.000                | 0.421                |
|            | 0.239                | 0.297                |
| SCP        | 1.000                | 0.165                |
|            | 0.703                | 0.213                |
| OT         | 1.000                | 0.468                |
|            | 1.000                | 0.455                |
| SS         | 0.436                | 0.468                |
|            | 0.407                | 0.455                |
| CST        | 1.000                | 0.466                |
|            | 0.371                | 0.391                |
| CS         | 1.000                | 0.450                |
|            | 0.770                | 0.754                |
| H1         | 1.000                | 0.366                |
|            | 0.287                | 0.185                |
| H2         | 0.724                | 0.157                |
|            | 0.348                | 0.287                |
| H3         | 1.000                | 0.491                |
|            | 0.449                | 0.226                |
| H4         | 0.205                | 0.188                |
|            | 0.157                | 0.194                |
|            | 0.157                | 0.142                |
|            | 0.185                | 0.142                |

Table S21: Resilience-sustainability regret index in the epoch ending in 2050

| Strategies | Epoch ending in 2050 |
|------------|----------------------|
| DN         | 1.000                |
|            | 1.000                |
| SCC        | 1.000                |
|            | 0.693                |
| SCR        | 1.000                |
|            | 0.275                |
| SCP        | 1.000                |
|            | 0.355                |
| OT         | 1.000                |
|            | 0.450                |
| SS         | 1.000                |
|            | 0.477                |
| CST        | 1.000                |
|            | 0.510                |
| CS         | 1.000                |
|            | 0.437                |
| H1         | 1.000                |
|            | 0.493                |
| H2         | 1.000                |
|            | 0.466                |
| H3         | 1.000                |
|            | 0.612                |
| H4         | 1.000                |
|            | 0.210                |
|            | 0.157                |
|            | 0.188                |
|            | 0.157                |
|            | 0.185                |
|            | 0.226                |
|            | 0.194                |
|            | 0.142                |
|            | 0.142                |

S8.2 Results on regret levels in the multiple domains of reliability-resilience-sustainability

Table S22: Reliability-resilience-sustainability regret index in the epoch ending in 2020 and 2025

| Strategies | Epoch ending in 2020 | Epoch ending in 2025 |
|------------|----------------------|----------------------|
| DN         | 0.809                | 0.875                |
|            | 0.745                | 0.695                |
| SCR        | 0.700                | 0.655                |
|            | 0.572                | 0.492                |
| SCP        | 0.355                | 0.265                |
|            | 0.297                | 0.249                |
| OT         | 0.532                | 0.520                |
|            | 0.316                | 0.316                |
| SS         | 0.608                | 0.755                |
|            | 0.724                | 0.529                |
| CST        | 0.510                | 0.537                |
|            | 0.357                | 0.357                |
| CS         | 0.459                | 0.571                |
|            | 0.326                | 0.281                |
| H1         | 0.531                | 0.554                |
|            | 0.544                | 0.586                |
| H2         | 0.468                | 0.493                |
|            | 0.429                | 0.341                |
| H3         | 0.437                | 0.466                |
|            | 0.353                | 0.298                |
| H4         | 0.573                | 0.612                |
|            | 0.527                | 0.440                |
|            | 0.210                | 0.149                |
|            | 0.204                | 0.251                |
|            | 0.187                | 0.139                |
|            | 0.127                | 0.231                |
Table S23: Reliability-resilience-sustainability regret index in the epoch ending in 2030 and 2035

| Strategies | Epoch ending in 2030 | Epoch ending in 2035 |
|------------|---------------------|---------------------|
| DN         | 1.000               | 1.000               |
| SCC        | 1.000               | 1.000               |
| SCR        | 0.744               | 0.235               |
| SCP        | 1.000               | 0.429               |
| OT         | 1.000               | 0.875               |
| SS         | 0.845               | 0.522               |
| CST        | 0.736               | 0.646               |
| CS         | 1.000               | 0.712               |
| H1         | 1.000               | 0.395               |
| H2         | 1.000               | 0.797               |
| H3         | 1.000               | 0.531               |
| H4         | 0.383               | 0.149               |

Table S24: Reliability-resilience-sustainability regret index in the epoch ending in 2040 and 2045

| Strategies | Epoch ending in 2040 | Epoch ending in 2045 |
|------------|---------------------|---------------------|
| DN         | 1.000               | 1.000               |
| SCC        | 1.000               | 1.000               |
| SCR        | 0.482               | 0.219               |
| SCP        | 1.000               | 0.408               |
| OT         | 1.000               | 0.872               |
| SS         | 0.624               | 0.433               |
| CST        | 1.000               | 0.581               |
| CS         | 1.000               | 0.846               |
| H1         | 1.000               | 0.353               |
| H2         | 0.816               | 0.331               |
| H3         | 1.000               | 0.503               |
| H4         | 0.470               | 0.153               |

Table S25: Reliability-resilience-sustainability regret index in the epoch ending in 2050

| Strategies | Epoch ending in 2050 |
|------------|---------------------|
| DN         | 1.000               |
| SCC        | 1.000               |
| SCR        | 0.517               |
| SCP        | 1.000               |
| OT         | 1.000               |
| SS         | 0.633               |
| CST        | 1.000               |
| CS         | 1.000               |
| H1         | 1.000               |
| H2         | 0.578               |
| H3         | 1.000               |
| H4         | 0.488               |

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S9. References

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