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Anticipating the Future in Urban Water Management: an Assessment of Municipal Investment Decisions

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Abstract

Municipalities are confronted with future uncertainties when they need to take decisions about their ageing water infrastructure. Previous work that addressed future challenges of urban water management focused mainly on climate change. This article develops a comprehensive index for forward-looking decisions about urban water management, to assess the extent to which, and how, Dutch municipalities anticipate the future with their investment decisions on urban water infrastructure. Results are based on a systematic comparison of investment decisions of 40 Dutch municipalities (about 10% of the population). Findings show that: 1) the extent to which municipalities anticipate the future differs largely; 2) only half of the municipalities adopt a long time perspective; 3) there are no commonly applied robustness tests; 4) flexibility is not explicitly adopted; rather, different flexible measures are applied; and 5) a minority of municipalities develop strategic visions or scenarios for urban water management to support decisions. These results highlight important areas of attention for municipalities worldwide. First, the need to invest in ageing water infrastructure can be seized as an opportunity to establish futureproof urban water management. Furthermore, climate change should be integrated with other future uncertainties into water management decisions. Third, transboundary cooperation could potentially increase municipalities' capacity to address uncertain futures and enhance learning. And last, increasing the use of scenario analysis and envisioning could help municipalities to prepare for the future. The index provided can be used for *ex ante* development and *ex post* assessment of investment decisions, to increase municipalities' preparedness for the future.

Keywords Forward-looking investment decisions · Municipalities · Future anticipation · Urban water management · Ageing infrastructure

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1 Introduction

Municipalities play a key role in reliable water supply and water sanitation services. However, the costs of water resources management are increasing due to future developments such as ageing populations, urban and agricultural pollution, economic trends, and climate change. These future developments will also increase the impact of water-related crises in developed and developing countries (OECD 2016) and shorten functional lifetimes of water infrastructure; but ageing infrastructure is already an investment challenge for governments worldwide (Hijdra et al. 2014; Selvakumar et al. 2015; Grigg 2017). Ageing infrastructure provides an opportunity as well as a challenge to consider often highly uncertain future developments when crucial and large financial decisions need to be made (Urich and Rauch 2014). It is therefore important to ascertain the extent to which municipalities are preparing for the future with their current investments in water infrastructure.

An interesting country to look at to assess future anticipation in water resources management is the Netherlands. As a low-lying delta region, the Netherlands not only faces many water-related challenges, but also has a strong reputation as a forward-looking pioneer country in water management (OECD 2014). However, literature that discusses future anticipation in Dutch and other regions of the world, often focuses solely on anticipating climate change (Lawrence et al. 2013; Dąbrowski 2017; Lyles et al. 2017), whereas there are many more future developments that governments will need to consider to prepare for the future and avoid disinvestment or even disruption (Herman et al. 2015).

Therefore, this article asks to what extent and how, Dutch municipalities anticipate the future (understood as a range of future developments) with their current investment decisions about urban water infrastructure. In answering this question, this article aims to make two contributions to existing literature. First, this article proposes a novel and comprehensive index of forward-looking investment decisions that can be used for *ex ante* and *ex post* evaluation of investment decisions in critical infrastructure by municipalities worldwide. The index builds on Pot et al.'s (2018) concept of a forward-looking investment decision, and combines technical as well as sociological aspects of future anticipation. Second, this index is then applied to systematically compare urban water infrastructure investment decisions made by a clustered sample of 40 Dutch municipalities (about 10% of the population). Results of this study reveal areas of improvement for future anticipation in investment decisions about water infrastructure, by showing differences among municipalities located in a frontrunner country in water management.

Section 2 introduces the conceptualisation and operationalisation of forward-looking investment decisions. Section 3 describes the data collection and analysis methods. Section 4 presents the results of a systematic case comparison of Dutch investment decisions about urban water management, followed by a discussion and a conclusion in sections 5 and 6.

2 Forward-Looking Investment Decisions on Urban Water Infrastructure

Anticipation means explicitly preparing for something (Anderson 2010; Granjou et al. 2017). Anticipation in the context of urban water management refers to preparing for a range of future developments, such as climate change and population growth, that can impact urban water systems (Van de Meene et al. 2011). The level of anticipation can be measured by analysing municipalities' investment decisions (Gersonius et al. 2013), understood here as governments' decisions to allocate financial resources to the realisation and renewal of urban water infrastructure. To measure the extent to which, and how, municipalities anticipate the future, this study builds on Pot et al.'s (2018) conceptual framework of forward-looking investment decisions. The concept of a forward-looking investment decision consists of a problem criterion (what future developments are recognised?); a solution criterion (can proposed solutions remain effective under future circumstances?); and a justification criterion (do decisions rely on probable, possible, or preferable future images?). The subsections below discuss the meaning and operationalisation of each of these criteria for urban water management.

2.1 Long-Term Problems Considered

First, the problem definition of an investment decision is forward looking when it includes future developments and adopts a time horizon of 10 years minimum to discuss these challenges. *Future developments* can for example be climate change, economic and demographic trends, socio-political trends, and technological developments (OECD 2014). Such developments can potentially impact the core functionalities of water infrastructure and can be highly unknown (Abbott 2005). Long term also implies that the decision takes on a *long-term time horizon* to understand the problem (Segrave et al. 2014). The technical lifetime of water infrastructure is typically long, 100 years or more. However, the functional lifetime of infrastructure can be shortened severely if investment decisions do not consider the far future to foresee any possible developments that may actually impact the effectiveness of the infrastructure during its lifetime (Herder and Wijnia 2012). Therefore, as a minimum, the time horizon within investment decisions should be 10 years to encompass future developments (Meuleman and in't Veld 2010).

2.1.1 Operationalisation of a Forward-Looking Problem Definition

To measure *forward-looking problem definition*, each future development mentioned in the investment decision is counted, and the number of future developments is multiplied by the presence or absence (1 or 0) of a long-term time horizon. This leads to the following formula: TOTAL#DEV * PRESENCE TH. If no long-term time horizon is mentioned in the investment decision, the forward-looking problem definition scores 0.

2.2 Robust or Flexible Solutions

Second, the chosen water management solution is forward looking when it aims to be robust, flexible, or both. *Robust solutions* are solutions that perform satisfactorily across a large range of plausible futures (Walker et al. 2013). In the specific case of wastewater treatment systems, Spiller et al. (2015) argue that robust systems need to remain functional for 25 years under changing conditions such as changing water demand. To assess whether water management systems will remain functionally effective over a long period of time, both the underground and the aboveground system need to be stress-tested. In the literature, various robustness stress-tests are proposed, including scenario analysis (Fletcher et al. 2017), extreme shower simulations (Urich and Rauch 2014), and climate change impact assessments (Zhou et al. 2012).

Solutions can also be *flexible* to cope with future developments. Flexibility implies that decisions about a water infrastructural solution leave options open for corrective or supplementary future measures after the solution has been implemented (Spiller et al. 2015). Flexibility includes piped solutions, aboveground solutions, and social measures. An important and flexible piped solution is to decouple rain and wastewater streams to free up space for changing precipitation patterns (Urich and Rauch 2014). However, to anticipate changing precipitation and other future uncertainties, underground solutions will not suffice. Several authors in the field of sustainable urban water management argue that flexible aboveground measures and blue-green infrastructure are increasingly important for municipalities (Porse 2013; Cettner et al. 2014; Carter et al. 2017). Last, to support the transition from inflexible sewerage and drainage systems to more flexible urban water management systems, Buurman and Padawangi (2017) stress the importance of including a social dimension, an important element of which is raising awareness and influencing behaviour.

To ensure flexibility, it is also important to monitor the effectiveness of the water management system (Kwakkel et al. 2016a). Flexibility then means that water managers adjust their social and infrastructural solutions in line with new information about changing circumstances and system performance (Brugge and Van der Roosjen 2015). This often requires new (forward-looking) decisions.

2.2.1 Operationalisation of a Forward-Looking Solution

To measure robustness, municipalities could earn a point for the application of I) underground and II) aboveground stress-tests that go beyond the standard precipitation patterns used for the system's design parameters. This leads to the formula: DRAINTEST + SYSTEMTEST, in which DRAINTEST refers to testing the urban drainage system itself and SYSTEMTEST refers to aboveground stress-tests.

To measure flexibility, municipalities could earn a point for investments in I) underground flexibility (i.e., decoupling of drainage systems), II) aboveground flexibility (e.g., water storage in parks), and III) social flexibility (e.g., public awareness raising campaigns). Furthermore, when a municipality uses monitoring information to adjust the system or future plans, it could receive an extra point for monitoring. This leads to the formula: DECOUPLING+ABOVE+SOCIAL(+MON).

2.3 Probable, Possible, or Preferable Futures to Support Investments

Third, the justification of an investment decision is forward looking when the decision relies on multiple scenarios, or on future goals or visions. *Scenarios* are used to intuitively sense possible futures as well as to explore uncertain future developments (Amer et al. 2013; Maier et al. 2016). According to both the intuitive and the exploratory scenario tradition, multiple scenarios will need to be used to grasp uncertain futures. Forward-looking decisions can also be based on *long-term goals* and *strategic visions* to identify the preferred future (Fryd et al. 2012). Governments may formulate long-term goals to reach specific future states (Meuleman and in't Veld 2010; Bai et al. 2015). A well-developed vision can be a starting point to establish anticipatory action, and visions in decisions can serve as an important justification for measures that are argued to be needed (Haasnoot et al. 2013; van der Voorn et al. 2015).

2.3.1 Operationalisation of a Forward-Looking Justification

To measure scenarios, I) the total number of scenarios (TOTAL#SCEN) and II) the future developments that are part of these scenarios (TOTAL#SCENDEV) are counted. This leads to the formula: TOTAL#SCEN * TOTAL#SCENDEV. Scenarios that municipalities use to support financial decisions regarding urban drainage tax are excluded, because these scenarios are not focused on understanding external developments.

To measure visions and long-term goals, different weights are used. Visions formulated as an integral part of the investment decision are assigned the heaviest weight, as these are specifically focused on the current investment decision on urban water management (compared with previously developed more generic visions) and present a holistic view on the future water management system (compared with future goals). The presence of future goals within decisions is weighted more heavily than reference to visions previously developed, because such goals are specifically formulated for the investment decision. Therefore: I) previously developed visions mentioned in the decision are weighted 0.5 (e.g., a water management plan); II) the formulation of long-term goals within the decision is weighted 1 (e.g., a goal to establish a climate-robust water management system); III) the formulation of a specific strategic vision within the decision is weighted 2 (e.g., a vision of future urban water management). This leads to the formula: (VISEX * 0.5) + (GOALS * 1) + (VISDEV * 2).

3 Methods

This section briefly describes the data collection and analysis steps, after an introduction to the Dutch context.

3.1 The Dutch Context and Choice of Investment Decisions

The entities responsible for Dutch water management are prescribed in the Dutch Water Act of 2009. Water management tasks are divided over the different levels of government. The national government is responsible for national water policy and for the operation and maintenance of the main water system by the National Water Authority (*Rijkswaterstaat*). Municipalities are responsible for local spatial planning, sewerage collection and wastewater transport, urban drainage (groundwater and rainwater), and storm water collection (OECD 2014). The local sewerage tax is used to finance investments in local water infrastructure. To justify the rate of this tax, all municipalities are required to have a valid Municipal Sewerage and Drainage Plan (MDP) according to the Dutch Environmental Management Act (1979). In this plan, municipalities have to describe the wastewater, storm water, and groundwater management measures in which they will invest in the upcoming period. The Dutch urban water management and sewerage foundation (*Stichting Rioned*) provides guidelines for the structure and content of these plans. These plans are therefore a consistent data source for a comparison of municipal investment decisions on water infrastructure.

3.2 Sample

A clustered sampling method was used to sample 40 municipalities out of the population of 388 Dutch municipalities in 2017. First, to ensure complete and comparable data (Ford and Berrang-Ford 2016), municipalities were excluded: 1) that were merged after 2010; 2) that needed additional payments from the Province between 2013 and 2016 and were therefore not financially independent, and 3) for which a large amount of information was missing about the municipality's characteristics and its water management systems in four *Rioned* surveys.

Additionally, to ensure a varied and representative sample, municipalities were selected on the basis of size (i.e., number of inhabitants) and soil type (i.e., soil factor). Soil factor refers to the weighted average share of different soil types (i.e., sand, clay, clay-peat, peat) within a municipality (Rioned 2013). Soil type can be a relevant difference between municipalities when investments in urban water infrastructure are being compared, because soil type impacts the structural deterioration of underground water infrastructure (Micevski et al. 2002).

3.3 Operationalising Forward-Looking Investment Decisions

The following formulae are used to assess the extent to which investment decisions on urban water management are forward looking:

- Forward-looking problem definition:
  (TOTAL#DEV * PRESENCE TH) +
- Forward-looking solutions:
  (DRAINTEST+SYSTEMTEST) + (DECOUPLING+ABOVE+SOCIAL + (MON)) +
- Forward-looking justification:
  (TOTAL#SCEN * TOTAL#SCENDEV) + ((VISEX * 0.5) + (GOALS * 1) + (VISDEV * 2))

3.4 Data Collection

The results of this study rely on an expert workshop, an analysis of municipal investment decisions, and 40 interviews with municipal water managers.

In July 2017, an expert workshop was organised in which three urban water managers, three academic urban water management experts, and one representative of the Dutch urban sewerage and drainage foundation participated. This workshop was used to discuss MDPs as a primary data source and to further conceptualise and discuss forward-looking decisions in the context of urban water management.

The collected investment decisions on urban water management consisted of the currently valid MDPs, municipal council decisions, council edicts, amendments, and MDP appendices (177 documents in total). Documents were collected through internet searching, accessing council databases, and – in eight cases – contacting the municipal registrar. Only one municipality had no valid MDP in place and was swapped with a municipality on a clustered sample backup list.

In September 2017, interviews were held with the municipal water manager of all 40 municipalities. All interviews were recorded. The interviews were used to 1) verify the coding of the MDPs and 2) gain additional insights into each municipality's way of working to prepare for the future, including for example the use of monitoring information.

3.5 Data Analysis

All MDPs and their appendices and decision documents were uploaded in the programme ATLAS.ti. Within ATLAS.ti, a high-level codebook was used with codes based on the operationalisations described in section 2. During the coding process when codes for the presence of forward-looking criteria were assigned, codes were also added inductively, mainly to code the specific solutions, robustness tests, future developments, and monitoring activities mentioned in the MDPs. At the end of the coding process, applied codes were double-checked, codes referring to the same thing were merged, and codes were compared across different MDPs to improve reliability and consistency.

The interviews were used as a member-check for the MDP analysis. Before each interview, the MDP analysis was shared with the interviewee. After each interview, the MDP analysis and the interviewee's transcribed comments were shared again. This resulted in factsheets for each municipality that were compared across municipalities to rank the municipalities according to their forward-looking score, discover similarities and differences between municipalities, and to sum the presence of forward-looking aspects across MDPs.

3.6 Limitations of the Methodological Approach

Although the MDPs form a consistent and comparable data source as argued in section 3.1, there are some limitations. The MDPs are obligatory investment plans that cover a period of four to six years. As a result, the implemented solutions can differ from the solutions mentioned in these plans. New insights, negotiations, politics, and events during the MDP period may have led to different implementation decisions (van Riel et al. 2015). In addition, some forward-looking solutions may have been executed without explication or reference in the MDP. To avoid important omissions, the MDP coding was verified and complemented with interviews. Third, the MDPs' start- and end-date were not the same for all municipalities. During the interviews, some municipalities noted that they were preparing a new MDP. In those cases, the version valid until at least the end of 2017 was used. The results focus on the presence and absence of forward-looking aspects within investment decisions of the overall sample, instead of assessing individual municipal capacities.

4 Results

This section describes the study's main findings by applying the forward-looking decision criteria presented in section 2. Section 4.1 first compares the overall scores on all forward-looking criteria between municipalities.

4.1 Extent to which Municipalities Anticipate the Future Differs Largely

Only 12 of the 40 MDPs analysed met all criteria of a forward-looking decision and included a forward-looking problem definition, solution, and justification. The average forward-looking score for the solution criterion is highest: 3.4; compared to 1.65 for problem definition and 1.99 for justification (see Fig. 1).

MDPs' level of forward-lookingness varied, with scores from 1 to 15.5. The highest possible score of a forward-looking decision is dependent on the number of future developments mentioned and could therefore potentially be higher than 15.5. Table 1 presents the index score that shows the extent of forward-lookingness of the current MDPs of 40 municipalities in the Netherlands.

Eindhoven scored highest by mentioning future developments of climate change, recovery of resources from waste, new technology for decentralised sanitation; by applying robustness tests with extreme shower simulations and two-dimensional simulation models; by including a combination of aboveground, underground, and social flexibility measures; by using monitoring to adapt; and by relying on a combination of climate change scenarios, a municipal water management vision, and a long-term national water vision, and on future goals for storm water, water quality, and climate change. The municipalities with the lowest score of 1, *Alblasserdam* and *Giessenlanden*, on the other hand, applied only decoupling of waste- and storm water; and *Giessenlanden's* MDP did not include any future developments. In the interview, *Giessenlanden* explained that it did not face acute problems with its water management system after peak rains in 2014 and that ongoing cost reduction efforts did not leave room for anticipating measures.

The four largest municipalities sampled, *Amsterdam, Den Haag*, *Eindhoven*, and *Rotterdam*, each with more than 220,000 inhabitants, comprise the top four in Table 1. The bottom of Table 1 on the other hand represents mainly relatively small municipalities, with the exception of *Den Helder* and *Middelburg*. A simple t-test confirmed that the average forward-looking score is higher for larger municipalities than for small municipalities ($n = 40$; $t = -3.29$; $p = 0.002$). *Middelburg*, as a large municipality with a low score of 2, noted in the interview that its MDP was 'outdated' and that it was preparing a new and broader MDP that would cover both underground and aboveground water management solutions. Newer MDPs could potentially meet more forward-looking criteria. Table 1 indeed shows that the nine highest-ranking municipalities all have MDPs that date from 2015 or later. The 10 lowest-ranking municipalities have MDPs from 2010, 2012, 2013, to 2015, with the exception of *Zundert* with an MDP from 2016. In the interview, *Zundert* explained that it consulted the larger neighbouring municipality of *Breda* for knowledge about future developments.

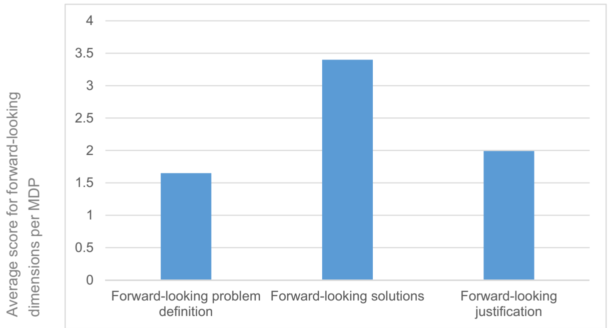

Fig. 1 Calculated average of the forward-looking problem definition, solution, and justification per municipal sewerage and drainage plan (MDP)

Table 1 Assessment of current municipal sewerage and drainage plans based on forward-looking criteria

Rank	Municipality	Forward-looking score	MDP start-date	Size (inhabitants)	Soil factor
1	Eindhoven	15.5	2015	223,898	1
2	Amsterdam	15	2016	790,110	1.32
3	Rotterdam	15	2016	616,260	1.32
4	Den Haag	14	2016	514,861	1.02
5	Barneveld	12.5	2016	53,521	1
6	Heemstede	12.5	2017	26,242	1
7	Dongen	11.5	2016	25,395	1
8	Hilversum	11.5	2015	87,175	1
9	Roerdalen	10.5	2017	20,699	1
10	Uithoorn	9.5	2013	28,307	1.35
11	Berkelland	8.5	2013	44,911	1
12	Koggenland	8.5	2014	22,345	1.24
13	Gorinchem	8	2016	35,206	1.4
14	Hoogezand-Sappemeer	8	2013	34,778	1
15	Krimpen aan den IJssel	7.5	2013	28,692	1.43
16	Medemblik	7.5	2017	43,117	1.26
17	Vlaardingen	7.5	2013	71,042	1.39
18	Appingedam	6.5	2013	12,053	1.31
19	Boekel	6.5	2017	10,119	1
20	Overbetuwe	6.5	2013	46,269	1.01
21	Cranendonck	6.5	2016	20,542	1
22	Rhenen	6	2015	19,253	1
23	Ooststellingwerf	5.5	2015	25,652	1
24	Woudrichem	5.5	2010	14,442	1.2
25	Hardinxveld-Giessendam	5	2011	17,654	1.43
26	Nieuwegein	5	2014	60,720	1.13
27	Tiel	5	2015	41,527	1.14
28	Voorst	5	2015	23,908	1
29	Laarbeek	4.5	2013	21,608	1
30	Lingewaal	4	2012	10,895	1.28
31	Noord-Beveland	4	2015	7416	1.1
32	Wageningen	4	2010	37,049	1
33	Zundert	3.5	2016	21,363	1
34	Beuningen	3	2013	25,433	1.01
35	Oudewater	3	2012	9850	1.48
36	Sliedrecht	3	2012	24,232	1.43
37	Den Helder	2.5	2013	57,065	1.09
38	Middelburg	2	2014	47,768	1.12
39	Alblasserdam	1	2015	19,467	1.37
40	Giessenlanden	1	2015	14,508	1.37

To verify the influence of soil type, the other sampling criterion with size, municipalities with a sandy soil were compared with municipalities with a non-sandy soil type. T-test values ($n = 40$, $t = 1.40$; $p = 0.05$) showed no meaningful difference between the forward-looking scores of the 21 municipalities with a sandy soil (average score 7.9) compared with those with a non-sandy soil (6.2).

4.2 Long-Term Problems Considered: Only Half of the Municipalities Adopt a Long Time Perspective

The most frequently reported future development within MDPs is climate change: 93% of the municipalities referred to climate change explicitly. Interviewees stated that awareness of climate change, its impacts, and local response options developed only gradually over the years. The *Den Helder* respondent, for example, observed a mildly increasing awareness of climate change within the municipality but also perceived climate change as a 'fashionable trend'. Some municipalities that did not address climate change argued in interviews that there was no urgency to act: they had not experienced any severe flooding or water nuisance issues (*Berkelland*, *Giessenlanden*).

To discuss climate change, five municipalities referred to the Dutch Delta programme or to climate scenarios of the Dutch Weather Institute (*KNMI*) and adopted the climate scenarios' 2050 time horizon. Half of the municipalities did not adopt any long time horizon to discuss future developments and to look beyond the MDP's time horizon. Besides climate change, future developments mentioned include spatial developments (55%), recovery of resources from wastewater (48%), sometimes also referred to as circular economy, and new technology (45%) (see Table 2). Recovery of resources from wastewater was included only in problem definitions or justifications, without translation to specific forward-looking solutions. Regarding spatial developments, municipalities often do not account for spatial developments until such developments are almost fixed with the inclusion of spatial projects in a spatial planning vision (expert workshop).

4.3 Robust Solutions: No Commonly Applied Robustness Tests

Municipalities used different robustness tests for their underground and aboveground water management systems (see Table 2). To test the capacity of the underground system, 38% used standardised showers based on actual rainfall patterns recommended by the Dutch urban water management and sewerage foundation. A quarter of the municipalities used the most severe standardised shower of 35.7 mm rain in 60 min to test the aboveground system. Other severe shower tests used consisted for example of 35.7 mm plus an additional 10% (*Giessenlanden*), 60 mm (10% of the municipalities), or 100 mm (10% of the municipalities). About a third of the municipalities (30%) applied more comprehensive stress-tests of the aboveground water management system that included multiple theoretical and/or past showers, and 8% uses two or three dimensional simulations Another third (33%) of the municipalities expressed the intention, in MDPs or during the interviews, to perform a stress-test. During the expert workshop, new standards to test the system were advocated because of already experienced and projected unpredictable weather; but there was no consensus or strong scientific basis for choosing one extreme shower over the other.

4.4 Flexible Solutions: Flexibility Was Applied although Not Explicitly Adopted

Only four MDPs included the word flexibility in relation to water management solutions, either connected to the measure of decoupling (*Middelburg*, *Noord-Beveland*) or expressing a general ambition to move towards more flexible systems to be able to incorporate adjustments based on changing insights (*Amsterdam*, *Eindhoven*). With or without reference to flexibility, all municipalities applied decoupling of wastewater and storm water flows. *Dongen* framed decoupling as an important 'climate measure'. Three quarters (78%) of the MDPs included aboveground measures. These measures covered a range of different solutions, such as: adjusting streets and green spaces to create additional water storage, creating water infiltration storage, and adjusting building

Table 2 Presence of forward-looking characteristics in municipal sewerage and drainage plans

Long-term problems considered	Count	%
Climate change (mainly water nuisance and precipitation)	37	93%
Spatial developments	22	55%
Recovery of resources from wastewater (sometimes referred to as circular economy)	19	48%
New technology (mainly related to new sanitation solutions)	18	45%
Demography (i.e., urbanisation, population decline)	7	18%
Increase of grey over green areas	6	15%
Legislation (mainly referring to new Dutch Environmental Planning Act to be adopted by 2021)	6	15%
Other sustainability topics (e.g., energy reduction)	4	10%
Hazards (e.g., explosions with dangerous goods, crisis management)	2	5%
Soil degradation	1	3%
Economy (i.e., national economic development, need for sustainable investments)	1	3%
Robustness or flexible solutions		
Robustness		
Stress-test with ≥2 theoretical and past showers	12	30%
35.7 mm stress-test developed by *Rioned* foundation	10	25%
Stress-test with Dutch / Belgian extreme rainfall event	4	10%
60 mm stress-test	4	10%
100 mm stress-test	4	10%
3D simulation	3	8%
2D simulation	3	8%
Flexibility		
Decoupling of storm water and wastewater streams	40	100%
Awareness raising (social)	25	63%
Use and creation of green for storage	14	35%
Streets as water storage and street profile adjustments	11	28%
Aboveground measures and aboveground storage (not specified)	14	35%
Stimulate private measures (social)	11	28%
Water infiltration storage	9	23%
Adjusting building standards	8	20%
Compensate private measures (social) (e.g., decoupling and green roof subsidies)	7	18%
Use and creation of surface water for storage	6	15%
Improvement of water flow with spatial planning	5	13%
Water permeable streets	1	3%
Water storage compensation	1	3%
Reserving space for water within foreseen spatial developments	1	3%
Justification with probable, possible, or preferable futures		
Reference to other visions	20	50%
Future goal: climate change	16	40%
Climate change scenarios Dutch Weather Institute	15	38%
Future goal: water nuisance	11	28%
Vision developed for MDP	8	20%
Future goal: sustainability (e.g., future generations, People – Planet – Profit, purchasing of materials)	8	20%
Future goal: decoupling	5	13%
Future goal: recovery of resources from waste water	5	13%
Future goal: energy reduction	5	13%
Future goal: water quality (mainly compliance with EU Water Framework Directive in 2027)	5	13%
Technical solution scenarios	2	5%
Future goal: environmental pollution	1	3%

standards (see Table 2). According to the interviews, municipalities still face barriers to taking aboveground measures. For example, it is difficult for municipalities to reserve space for water at potentially suitable storage locations before new spatial plans are drawn up (*Barneveld*). Also, according to *Oudewater*, its weak soil is a barrier to aboveground water infiltration storage. The respondent of *Den Helder* pointed towards a lack of priority for economic reasons and a backlog in data management.

To support aboveground solutions, a large majority of the municipalities (63%) invested in the social measure of awareness raising. *Rotterdam* and *Amsterdam* also proactively stimulated private partners and citizens to apply water management measures such as green roofs. Expert workshop participants perceived it as risky to rely on privately owned green infrastructure as part of the urban water management system, because this infrastructure can be prone to change: a new house owner may again pave his entire garden despite the government subsidising the previous house owner to create a rain garden. Paving gardens reduces a city's porosity (Fryd et al. 2012).

To be able to adjust measures to changing insights, only six municipalities used monitoring of system data, such as overflows, precipitation, citizen complaints, pumping stations, or infiltration basins. The remaining 85% of the municipalities were still in the process of collecting or analysing data. From the interviews, it emerged that municipalities rely strongly on their own knowledge of the system and actual experience with flooding rather than on structural system signals, something that van Riel et al. (2015) also showed. The expert workshop also called for more attention on learned adaptation, by monitoring information.

4.5 Justification with Probable, Possible or Preferable Futures: Uncommon to Develop Visions or Scenarios for Urban Water Management

None of the municipalities developed scenarios to justify measures in their MDPs. This was confirmed by the expert workshop. Table 2 shows that 38% of the municipalities refer to *KNMI's* existing national climate scenarios; but often municipalities treated these scenarios as one, summarising the main points from the four *KNMI* scenarios (e.g., *Krimpen aan den IJssel*, *Koggenland*, *Barneveld*). In the expert workshop, one participant said that referring to *KNMI* scenarios provides a 'false security' about the future, because national scenarios cannot account for local system specifics and unknowns. Paradoxically, water managers start to recognise uncertainties such as climate change or population growth when these uncertainties are no longer uncertain but real, through for example extreme rain events or plans for a new city quarter (expert workshop).

Only 20% of the municipalities specifically developed visions for the MDP. For spatial developments such as a new city quarter, water managers relied on the local spatial planning vision (*Structuurvisie*), but the future in this vision is not an uncertainty but a 'future truth' according to the expert workshop. Also, municipalities referred to visions from a decade earlier such as water management plans of 2006 and 2007 (*Vlaardingen*, *Den Helder*, *Krimpen aan den IJssel*). Lastly, a large majority of the municipalities (70%) formulated long-term goals in their MDPs, most often related to climate change (40%) or water nuisance (28%) (see Table 2). Five (13%) municipalities formulated a specific long-term goal of decoupling storm and wastewater flows (e.g., to decouple 10% of the existing combined waste- and storm water systems in 20 years' time, *Barneveld*).

5 Discussion

This article presents the first attempt to build a forward-looking index for the field of water management. The operationalised framework and index of forward-looking decisions developed in this study can increase the future-awareness of municipalities in two ways. First, the framework can assist with the development of forward-looking investment plans (i.e., *ex ante* application of the framework). Second, the framework can be used to assess investment decisions (i.e., *ex post* application of the framework) as shown in this study.

Applying the forward-looking decision framework to municipal investment decisions provides urban water managers and municipal decision makers with a number of key insights.

First, and *overall*, an important finding is that anticipating the future is clearly not self-evident for Dutch municipalities. This is surprising for two reasons: first, because the Netherlands is often portrayed as a leader in water governance and climate change adaptation (OECD 2014; Kwakkel et al. 2016b; Kamperman and Biesbroek 2017); second, and more importantly, because the long lifetimes and lead-in times of implementing new infrastructure are not necessarily translated into forward-looking decisions (Meuleman and in't Veld 2010; Herder and Wijnia 2012; Gersonius et al. 2013). The low incidence of forward-looking aspects within many Dutch municipalities' investment decisions raises doubts about whether the water management systems built today will be effective over a long period of time (Gregersen and Arnbjerg-Nielsen 2012). Ageing water infrastructure provides an opportunity that municipalities should seize to invest in the future of urban water management.

Second, this study's results show that there are still considerable gaps in the *future developments* that municipalities address and the possible developments that can impact their critical infrastructures. Municipalities anticipated climate change mainly with their investment decisions on urban water infrastructure, and climate change was mainly interpreted as water nuisance. Anticipating climate change impacts, however, also calls for attention on urban heat islands, drought, and flood risks (Koop et al. 2017; Forzieri et al. 2018). Furthermore, other important future uncertainties possibly impact urban water infrastructure, for example ageing, growing or shrinking populations, soil degradation, and environmental pollution (Ferguson et al. 2013). Municipalities worldwide will need to integrate climate change with potential future uncertainties into a water management modelling-and-decision framework to ensure sustainable living environments and avoid major disruptions (Díaz et al. 2016; Fletcher et al. 2017).

Third, ensuring *flexibility* and *robustness* to respond to future uncertainties will require not only flexible measures and robustness tests but also learning to adjust (Koop et al. 2017). Municipalities in this study often treated climate change scenarios as one, or they applied only one precipitation scenario in a robustness test. This is more a predict-then-act approach than an accommodation of change (Gersonius et al. 2013). Very few municipalities monitored the performance of their water management system to make incremental adjustments as advocated by real options (Urich and Rauch 2014), adaptive management (Pearson et al. 2009), and sustainable urban water management (Fryd et al. 2012). Monitoring and evaluation of decisions are key for anticipation. If capacity to do so is a problem, reported by the OECD to be the "Achilles' heel for sub-national governments" (OECD 2016, p. 12), it may be a good idea to strengthen or establish multi-level networks. Transboundary cooperation could stimulate learning and adaptive action (Hill Clarvis et al. 2013).

Last, to strengthen governance capacity for forward-looking decisions, potential lies in the use of *scenarios* and visions; this was found to be limited in this study. Scenario analysis within strategic planning can help to identify different strategic options needed to confront future uncertainties (Dominguez et al. 2011). Cettner et al. (2014) show how visions can help to reframe dominant views and establish innovative ideas for sustainable urban water management. Scenario analysis and envisioning, preferably in participatory processes, can increase the diversity of future perspectives, help to identify blind spots and alternative strategies, and stimulate learning (Head 2014; Tschakert et al. 2016). Although time intensive, scenario analysis and envisioning can therefore be important tools for municipalities to prepare for the future and improve investment decisions.

The index of forward-looking decisions is novel and therefore not perfect yet. This study has its limitations and offers several avenues for future research. First, this study was based on assessing investment plans of municipalities located in one frontrunner country in water management. To discover how less advanced, and potentially more vulnerable, countries prepare for the future, the index can also be used to compare municipalities from different countries. Second, this study provided a snapshot analysis of currently valid investment plans, but with the index it will be possible to track progress over time (Lesnikowski et al. 2016). It is recommended to repeat this study to compare multiple investment decisions by the same governments to stimulate learning. Third and last, this study was mainly descriptive to enable the harvesting of all aspects of forward-looking decisions. An explanatory study could test the specific factors that impact decision making, such as participatory processes, multi-level networks, and leadership, to enable municipalities to successfully anticipate the future.

6 Conclusion

Municipalities are confronted with future uncertainties when they need to take decisions about their ageing water infrastructure. This article systematically compared 40 Dutch municipalities' investment decisions on urban water infrastructure to assess the extent to which, and how, municipalities anticipate the future with their current investment decisions on water infrastructure.

This article developed an index for forward-looking decisions on urban water management that can be used for *ex ante* development and *ex post* assessment of investment decisions on urban water infrastructure, to increase municipalities' level of preparedness for the future. The results of applying the index to a sample of Dutch municipalities showed that, despite the long lifetime of water infrastructure and the respected reputation of Dutch water management, the extent to which municipalities anticipate the future differs largely. Larger municipalities were found to be more forward looking than smaller ones. The results also provide an overview of relevant future developments, robustness tests, and flexible strategies that municipalities worldwide could consider to anticipate the future. This study showed that Dutch municipalities most often anticipated climate change and only half of the municipalities adopted a long time perspective to discuss future developments. To ensure the long-term effectiveness of urban water management solutions, municipalities used different robustness tests with often limited scope. Flexibility is not yet a concept that is fully embraced, although municipalities did invest in different flexible measures such as decoupling, water storage in parks, and social awareness campaigns. What is also striking is that less than a quarter of municipalities developed strategic visions or scenarios to better grasp uncertainties before investing in urban water management. Using envisioning or scenario analysis before making investment decisions on new and ageing water infrastructure can potentially help municipalities worldwide to acknowledge a range of future uncertainties and formulate different strategic options to cope with these.

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Compliance with Ethical Standards

Conflict of Interest None.

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