Water Research 178 (2020) 115780

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

Multiple perspectives of resilience: A holistic approach to resilience assessment using cognitive maps in practitioner engagement

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ARTICLE INFO

Article history:
Received 23 November 2019
Received in revised form
11 March 2020
Accepted 1 April 2020
Available online 9 April 2020

Keywords:
Resilience
Risk screening
Vulnerability
Co-production
Cognitive maps
Wastewater management

ABSTRACT

Resilience has become a regulatory concept influencing investment decisions in the water and wastewater sector. However, current assessments predominantly focus on technical resilience and on engineering solutions. Here we propose an alternative, more holistic approach that captures multiple perspectives of resilience by eliciting and comparing cognitive maps of diverse agents both from within as well as external to a wastewater utility. We use Fuzzy Cognitive Mapping as a practical tool to elicit subjective views on resilience mechanisms and illustrate the methodology in co-production with professionals from the wastewater sector in the Belfast area (Northern Ireland). We find that the proposed participatory process facilitates a more "reflective", "inclusive" and "integrated" assessment than current approaches. Screening for risks and vulnerabilities using this new approach can foster an integrated system perspective by (i) systematically identifying connections between (sub)systems which are normally assessed separately, (ii) detecting feedbacks between system components which may reveal unintended consequences of resilience interventions and by (iii) obtaining a wider portfolio of potential interventions to increase overall resilience. We conclude that the suggested approach may be useful for strategic planning purposes within a utility and for improving cross-departmental communication among both internal and external agents.

1. Introduction

Resilience has been at the centre of recent reflections on sustainability in the water and wastewater sector. It expands the usual scope of service reliability under standard loading to exceptional low probability/high impact events which have traditionally been neglected (Butler et al., 2016). The concept of resilience has become increasingly popular and is used in investment decisions. However, the focus of resilience in the water and wastewater industry is still predominantly technical in nature (Mullin and Kirchhoff, 2018).

In addition, despite interdisciplinary ambitions of the resilience community, the scientific literature shows that there are important dialectical forces at play between the natural/engineering sciences (resilience) and the social sciences (vulnerability) that are shaped by different world views and interpretations (Olsson et al., 2015). The distinction between engineering resilience, which aims at maintaining "efficiency of functions" and ecological resilience which aims at maintaining "existence of functions", "are so fundamental, that they can become alternative paradigms whose devotees reflect traditions of a discipline or of an attitude rather than a reality of nature." (Holling, 1996). Similarly, resilience has different meanings in wastewater management, depending on the specific domain and objective it is applied to (Juan-García et al., 2017).

In this paper, we intend to move beyond the variety of definitions that exist in the literature (Juan-García et al., 2017) and do not seek a precise definition of resilience at the onset of our study. We are interested in revealing how wastewater management practitioners perceive vulnerabilities and resilience of the wastewater system they are working in.

Our goal is twofold: firstly, to propose to practitioners a methodology that contributes to a better understanding of the wastewater system under study, bringing together various points of view that usually do not meet. Secondly, to contribute to addressing some of the gaps that Juan-García et al. (2017) identified in the wastewater sector (Table 1), to foster incorporation of resilience in wastewater management practice.

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https://doi.org/10.1016/j.watres.2020.115780

Table 1
Gaps identified in the literature and how we expect this study to contribute to addressing them.

Gaps identified in the literature on resilience of wastewater systems	How we expect our study to address these gaps
There is no common definition of resilience.	Each participant can present his/her personal view on resilience depending on his/her experience, knowledge and beliefs. We do not seek to define resilience at the onset of the study. We make use of participants' subjectivity to elicit multiple perspectives of resilience.
Properties of resilience need to be "*reflective, inclusive and integrated*".	Our approach facilitates an assessment of resilience that is *reflective* (reflects experiences of practitioners in a discussion with the analyst that includes a cognitive mapping exercise of causal networks), *inclusive* (invites and includes participants of diverse responsibilities covering relevant internal and external actors), *integrated* (enables to account for feedbacks to and from other urban resources and frameworks; the comparison of the maps allows to obtain an integrated view across departments).
A comprehensive study of stressors to understand all potential vulnerabilities is lacking.	We identify and invite a wide set of agents in order to obtain a holistic view on potential vulnerabilities. We let participants interpret the word "resilience" themselves and to specifically include drivers that work on different spatial and time scales.
Resilience assessments are usually focused on physical stressors and technical interventions.	We include departments such as human resources, financing, legal, governance, environmental regulation to avoid over-focus on physical stressors and technical/engineering aspects of resilience.
There is a lack of qualitative assessments that integrate legal, social and governance variables into the physical assessment and that help understand extreme uncertainties.	
Complementarity, connection and feedback of the wastewater framework to other systems, urban resources or broader asset management plans is missing.	We include external agents such as sister departments, for example, roads, energy, infrastructure, transport, environment, encouraging participants to take a wide view on how the wastewater sector is embedded in urban and natural landscapes and processes.
There is a need for a standardised resilience framework that is flexible enough to capture specificities and allow its application in different case studies and enable comparison between cases.	The application of our approach to different contexts and sites will naturally highlight different dominating themes. Thus, qualitative comparisons are made possible. In addition, by adapting the interview question the approach has the potential of transferability to a broad range of specific subjects and domains.
To test the effectiveness of interventions, these have to be assessed holistically.	By facilitating a holistic assessment and eliciting propagation mechanisms of resilience through multiple causal networks that reveal feedback loops we facilitate the identification of unintended consequences.
There is a need for a framework that could be directly applicable by practitioners.	Our approach is relatively parsimonious and user-friendly.

Note: Gaps identified are based on the literature review of Juan-García et al. (2017).

To do this, we develop an approach in which, starting from open-ended questions, we obtain cognitive maps in an engagement process with wastewater professionals. Cognitive maps are graphical illustrations of a person's "internal associative representations" (Gray et al., 2015). These representations are elicited with logical structures such as causal diagrams.

We test this new approach for the Belfast area with NI Water (Northern Ireland Water) where we obtain multiple perspectives of resilience, informed by a wide range of agents, both internal and external to the water utility. Our approach enables to identify opportunities for change, conflicting issues as well as potential barriers and unintended consequences of resilience interventions which may not be revealed by more narrowly defined resilience perspectives.

It facilitates the development of a "reflective", "inclusive" and "integrated" view of resilience, features that have been found to be largely missing in current practices (Juan-García et al., 2017). This permits to obtain a broader view in which human-driven resilience complements technical resilience and in which different urban systems and resources are interlinked (Table 1). The holistic assessment therefore may uncover more meaningful resilience interventions that address vulnerabilities at their origin.

The methodology is intended for screening purposes prior to targeting specific resilience aspects with more technical and quantitative approaches including statistical and phenomenological modelling (Carpenter et al., 2009; Oppenheimer et al., 2007).

The following sections present our resilience screening approach (Section 2) and the results from its application to the Belfast wastewater system (Section 3). Section 4 discusses to what extent our study contributes to address some of the gaps identified in the literature and its potential value added for the water industry in general. Section 5 concludes with a summary of the main findings.

2. Methodology, materials and case study

With origins in cognitive psychology, which studies human learning and behaviour, cognitive maps are graphics for structuring and illustrating knowledge and beliefs (Gray et al., 2014). Cognitive maps are drawn around a specific question of interest by agents that are familiar with this domain. Thus, participants can structure, visualise and share their experience, understanding and interpretation.

2.1. Fuzzy Cognitive Mapping

Fuzzy cognitive mapping (FCM) is an extension of cognitive maps, characterised by the use of cause-effect relationships to link cognitive concepts (Axelrod, 1976). In addition, FCM enables to indicate the perceived strength of cause-to-effect relations (Kosko, 1986) including for complex and abstract variables such as "Responsibility" or "Political will" which may be difficult to quantify otherwise (Özesmi and Özesmi, 2004).

Fuzzy cognitive maps have been reported to be of particular interest in domains characterised by complexity, vagueness, uncertainty, subjectivity and data scarcity (Gray et al., 2014). As cognitive maps, FCM allows to capture knowledge, experience and beliefs from participants about the functioning of a specific system to "make [such] implicit assumptions (or mental models) explicit" (Jetter and Kok, 2014). This is done during interviews in which professionals identify core variables and their interrelations using causal diagrams. Participants characterise the influence of one variable onto another by assigning a positive or negative sign and a metric between 0 and 1 (where 0 indicates "no influence" and 1 a

"very strong influence").

Interviews are based on one or several open-ended questions that are the leading thread through the entire mapping process. The analyst's role is to guide the participants through the mapping exercise and mediate between the practical experience of practitioners and the requirements of the elicitation methodology. Participants take part in the process either in individual interviews or in working groups. In the latter case, participants discuss their views, cause-to-effect relationships, signs and strengths of each connection that altogether lead to a common model.

Because there are no requirements on the interview question itself, FCM is a flexible tool with many different possible applications. Beyond its initial use in the psychological realm, FCM has also been applied to topics as varied as the potential deployment of photovoltaic solar panels (Jetter and Schweinfort, 2011), vulnerability assessments of livelihoods (Murungweni et al., 2011), risk assessments (Medina and Moreno, 2007) including financial systemic risk (Mezei and Sarlin, 2016), environmental management applications and ecology (Mehryar et al., 2017; Özesmi and Özesmi, 2004), water resources management (Kafetzis et al., 2014) and climate change research (Olazabal et al., 2018; Reckien, 2014).

2.2. A holistic resilience assessment approach

2.2.1. Defining the objective and interview questions

To set up the participatory experiment, we design a questionnaire (Appendix A1 of the Supplementary Materials) that seeks to address the problematic at hand while guiding the participants through the mapping process. The development of the questions results from interactions with NI Water senior managers and reflections about the focus and objective of our study on *capturing multiple resilience perspectives and obtaining a broad set of potential interventions*. The interview guidelines address two questions that shall be elicited during the interviews:

> Question 1. *According to your experience, knowledge and expertise how are drivers and characteristics of the system affecting resilience of wastewater management at Northern Ireland Water (NI Water) for the Belfast area in the short, medium and long term?*
>
> Question 2. *According to your experience, knowledge and expertise which interventions/changes could increase resilience of wastewater management at NI Water for the Belfast area in the short, medium and long term?*

We deliberately chose to leave "*the system*", "*resilience*" and "*Belfast area*" undefined, with the intention that the participants specify boundaries and reveal their own interpretations of these concepts. Besides, we introduce the notion of timescales (short-, medium- and long term), in order to capture the widest possible range of resilience drivers that can be identified and reduce the bias towards short term priorities that professionals deal with on a daily basis.

2.2.2. Identifying relevant participants

Motivated by the idea of widening the range of resilience perspectives, the aim is to conduct mapping sessions with representatives from all departments and several hierarchical levels of the wastewater utility. In addition, we identify principle agents as potential interviewees outside NI Water. In view of identifying relevant participants we conduct a series of preliminary meetings with the heads of departments at the water utility. In some cases, one professional is selected to represent a department and individual interviews are conducted. In other cases, several people representing different areas of responsibility within the same department are nominated to participate in a group interview.

2.2.3. Planning the mapping sessions

We plan resilience mapping sessions to last 90 min with the interest of encouraging experts' participation balancing their limited time availability with the need to introduce them to the methodology and develop the narratives and maps. At the beginning of the mapping sessions, the analyst needs to guide the participants step-by-step through the interview guidelines (Appendix A1) and to clarify any questions and doubts that arise. During the interviews the analyst needs to assimilate as well as possible the knowledge of the participants and ensure it is correctly captured according to the requirements of the FCM methodology. This necessarily demands a dialogue between the analyst and the participants.

2.2.4. Conducting mapping sessions

Mapping sessions are structured in three different phases (Olazabal et al., 2018) (see Appendix A1).

In the first phase, participants are given time to individually brainstorm on the first interview question about drivers and characteristics of the system that affect resilience. They are then invited to start drawing the map with one of the concepts they have identified and to add further concepts revealing the cascading cause-to-effect relations. If participants do not feel comfortable with the drawing process, the analyst can step in and draw the map based on the instructions of the participants. The process finalises once participants feel they have covered all their concerns.

In the second phase, the same process is followed with the second interview question on resilience interventions.

In the third phase, interviewees are asked to reflect on the sign and strength of each connection. The positive sign of a relationship refers to a positive influence of one variable on another (variables move in the same direction) while a negative sign means a negative influence (variables move in opposite directions). Weights are proposed to be a decimal number on a scale between 0 and 1 referring to the strength of each cause-to-effect linkage between two variables.

2.2.5. Narratives of resilience maps

To be able to capture the storyline revealed in the interview we solicited agreement from the participants to be able to voice record the sessions that are later transcribed by the analyst (for confidentiality reasons these are not available to the reader). These recordings and transcripts serve to develop a qualitative narrative that supplements the maps and facilitates comparison between them. This also allows to obtain clarifications of elicited resilience drivers and rationales of system mechanisms and to revise maps if necessary.

2.2.6. Digitalisation of resilience maps

The digitalisation process consists in a post-processing of hand-drawn maps. It includes a structuring of the information, clarifying of concepts, removing relations that are double counted, revising incoherencies encountered and the translation of the causal diagrams into matrices.

2.2.7. Storylines and analysis

To complement the maps, the accompanying narratives are captured. In order to do this, the transcripts of the interviews are used to develop two types of accompanying documents. For each meeting the "Storyline" provides a summary of resilience mechanisms as uncovered in the original interview and the "Analysis" provides information about i) the analysts' interpretation of debated topics that are seen as potentially valuable points to

further explore (content) and ii) methodological FCM related issues that may have been encountered during each interview (methodology) (Appendix A4).

2.2.8. Comparing resilience maps

The analysis of multiple perspectives of resilience is obtained by comparing maps and storylines across interviews and by disentangling various resilience and vulnerability propagation mechanisms as elicited by the participants.

We initially identify main themes that were discussed in all interviews. Each map is then screened for concepts that relate to each of these themes so that resilience variables can be grouped accordingly. Any new theme that is not previously listed and that surfaces through the single map analysis can be added.

For each resilience theme the analyst then identifies common and divergent mechanisms at work in the different resilience perspectives within and across maps.

3. Results

3.1. Belfast case study

In our case study 15 mapping sessions were conducted with a total of 31 internal and external participants from different backgrounds and areas of responsibility (Appendix A2). The mapping sessions took place during November 2018.

The analyst needed to clarify the methodology to agents as these were often more familiar with process engineering diagrams rather than with causal diagrams. The analyst also invited participants to elaborate further on their explanations to be able to capture their rationale.

Recordings and transcripts ensured that the original information could be accessed when processing the data. The analyst worked with the resulting maps (Appendix A3), narratives and storylines (Appendix A4) in parallel, in order to clarify resilience mechanisms and to analyse core themes as well as similarities and differences between resilience discourses that are examined in section 3.2.

3.2. Emerging resilience themes in Belfast

In this section we examine what kind of information our suggested approach allows to reveal.

In our analysis of resilience issues with regard to wastewater management specific to the Belfast area we identify and explore in the next paragraphs seven relevant resilience themes.

In each subsection we disentangle similarities and divergences across maps. We additionally explore the interconnectivity among themes.

3.2.1. Capacity

In Belfast, capacity emerges as a central cross-cutting issue touching upon the different aspects of resilience.

Illustratively, map 10 (Fig. 1) displays typical capacity limitations that are usually considered in the wastewater system: drainage capacity and wastewater treatment plant capacity (in terms of volume and quality). It specifically relates capacity with investment for storm tanks, maintenance of ageing assets to avoid sewer blockages and technology to improve effluent quality and monitoring.

In other maps, participants related “capacity” to other complementary issues that are further elaborated in other sections. They include:

- divergent interests and a lack of alignment among governmental departments that may generate inefficiencies (see section 3.2.3),
- the misuse of sewers that create frequent blockages and opportunity costs for the utility as well as illegal discharges into sewers and water bodies (see section 3.2.4),
- the capacity to meet standards (see section 3.2.5),
- skills and labour capacity that may put service delivery at risk and slow down innovation (see section 3.2.6).

Various insights on unintended consequences are obtained. Firstly, incineration effluents of sludge treatment can potentially put a wastewater treatment plant at risk of insufficient capacity (map 5). Secondly, as a consequence of shutting down frequently spilling combined sewer overflows, more water is diverted to treatment plants exacerbating the capacity of networks and treatment (map 5). Thirdly, as improvements in treatment efficiency lead to better effluent quality, regulations may be further tightened which puts additional pressure on the utility (map 1). Lastly, increased drainage and treatment capacity is considered to allow for economic growth which is commonly regarded as a driver of social welfare. However, economic development can have major consequences on the production of wastewater as well as on the acceleration of storm water runoff through increased soil imperviousness (map 11). This then reduces drainage and treatment capacity (map 2), eventually putting a strain on development objectives (map 8, map 13, map 14). Such negative feedbacks can also be envisaged alternatively: if economic growth is oriented towards appropriate channelling of funding (map 14), for example towards solutions such as sustainable urban drainage system (SUDS), then development constraints themselves can become opportunities for further economic growth (map 7).

The portfolio of interventions to increase capacity spans across various domains (Table 2). Besides engineering- and “hard” infrastructure solutions, “soft” interventions emerge to be equally important. Examples include the value of human capital in order to retain fundamental knowledge in the company (map 4) and policy alignment to foster coherent policies in separate departments.

3.2.2. Costs, finance and investment

Limited funding in the Belfast wastewater sector has been historically leading to considerable investment needs (map 15 – narratives). To address these, the Living with Water Programme (LWWP) has recently proposed a drainage and wastewater investment programme with a budget of approximatively £ 900 M over the next 10 years (map 12). Its objectives are to reduce the flooding risk in Belfast, comply with environmental legislation (for example, the Urban Wastewater Treatment Directive and the Water Framework Directive) and enable regional growth that has been constrained due to a lack of drainage and treatment capacity.

Ten out of 15 maps acknowledge funding and investment as a central component for resilience (map 1, map 2, map 3, map 5, map 6, map 8, map 10, map 12, map 13, map 15). The wastewater sector is highly capital intensive and constantly forced to keep pace with change: firstly, urban development puts the wastewater sector under pressure because of the associated increasing sewer and drainage capacity requirements (see section 3.2.1). Secondly, the wastewater sector needs to permanently adapt to tightening discharge standards (map 1, map 5, map 10, map 11) (see section 3.2.5). This involves a complex dynamic between how fast the capacity requirements of the wastewater sector can react to changing demands from economic growth and shifting societal behaviour and norms. At the same time, the frequent drain blockages generate recurrent repair interventions in the city (map 3, map 11, map 12) which represent a high opportunity cost in terms of regular base

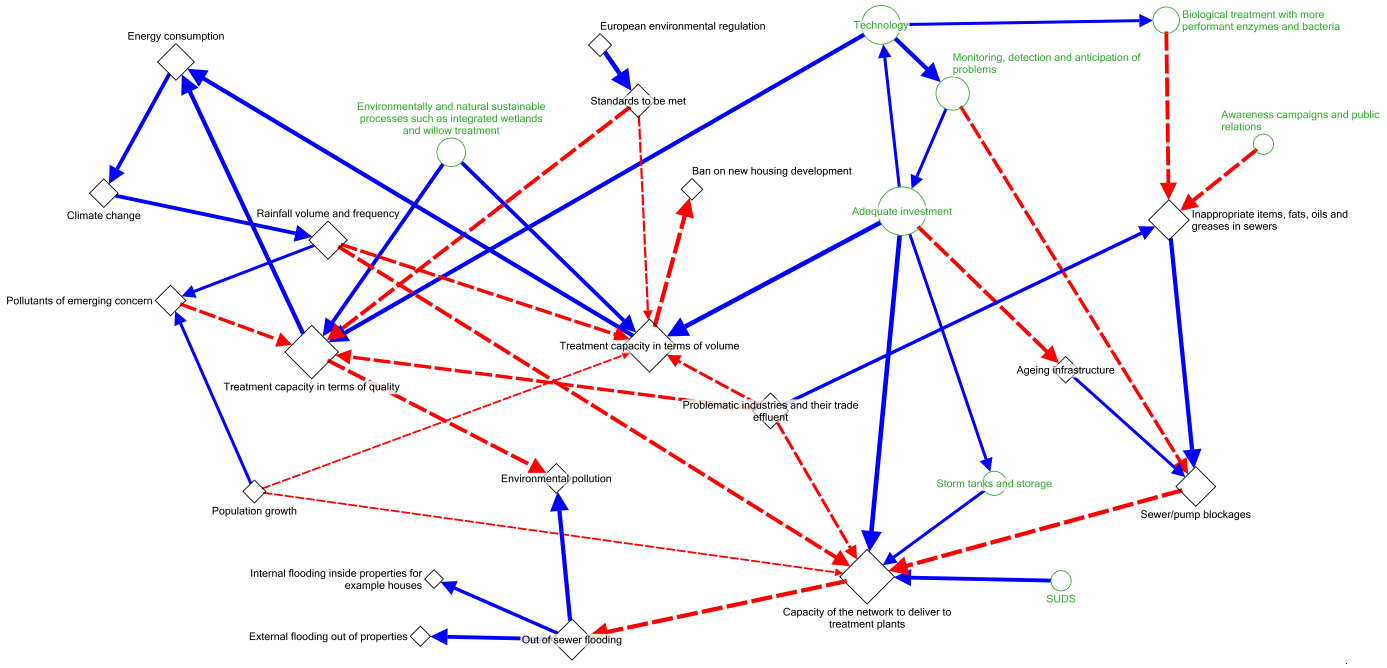

Fig. 1. Resilience map 10 highlights different types of capacity limitations in wastewater infrastructure and propagation mechanisms of resilience drivers. Blue (full) arrows indicate a positive influence (for example an increase in concept A leads to an increase in concept B) whereas red (dashed) arrows indicate a negative influence (an increase in concept A leads to a decrease in concept B); black diamonds are system concepts related to resilience and vulnerability; green circles indicate elicited interventions to increase resilience. The size of each diamond and circle reflects the centrality which is the sum of the absolute values of all incoming and outgoing connection weights (degree centrality).

Table 2
Interventions that improve capacity directly or indirectly.

Type of intervention	Intervention	Map
Awareness and Education	Awareness campaigns	1, 10
	Educational programmes celebrating pilot projects with successes and the promotion of positives	6
	Education, awareness and social responsibility for wastewater production and sewage usage	11
	Customer awareness to affect behaviour including water consumption	13
Structure	Sustainable urban drainage systems (SUDS)	5, 7, 8, 10, 12, 14
	Storm-water separation	7, 8, 14, 15
	Storm tanks	5, 10
	River catchment management	8
	Environmentally and natural sustainable processes such as integrated wetlands and willow treatment	10
	Runoff attenuation schemes by private developers	12
Funding	Funding and human resources	1
	Government budget for wastewater management	2
	Capital funding	3, 6, 8
	Adequate investment/funding	10, 12
	Investment in surface water management and drainage	12
	Water and wastewater charges	6, 8, 13
Human resources	Funding and human resources	1
	Access to labour	2
	Diversity of employment pool	4
	School campaigns for students in subjects such as science, technology, engineering and maths	4
	Career development plans	4
	Phased retirement policy	4
	Training of new young workers	4
Policy alignment	Interdepartmental policy alignment (building regulations and planning, road services, public realm)	6, 11
	Alignment of investment proposals and aspirations	9
	Adequate urban planning to include and address wastewater issues	12
Technology	Technology (improvements/innovation)	10, 14, 15
	Artificial intelligence and deep learning	14
Maintenance	Maintenance, management and replacement	1
	Maintenance of drainage infrastructure	8
Information accuracy	Network data accuracy	6
	Optimisation and integration of information	9
Others	Environmental modelling for targeted remediation	11
	Political will	8
	Climate change mitigation	8
	Monitoring for detection and anticipation of problems	10
	Regional Community Resilience Group	12

maintenance (map 11).

It was highlighted that as a state-owned company, regulated by a regional economic regulator, the utility (NI Water) has little financial autonomy on budgets and decisions regarding total, capital and operational expenditures (TOTEX, CAPEX and OPEX) as well as on salary levels (see section 3.2.6). According to some interviewees there is also a strong political barrier regarding the introduction of sewage and water charges that could reduce wastewater volumes due to lower water consumption (see section 3.2.3).

Alternatively, some participants argued that even when the utility does not get all the funding it requests, the most important investments usually do get funded and that together with reprioritisation (map 12 - narratives) as well as risk management the highest possible value for the money invested can be obtained (map 13 - narratives). Other participants, identified drivers that can facilitate a more effective use of available funds (map 9): it was argued that accurate information (map 9), network data (map 6) and monitoring (map 10) may demand some initial financial support (map 10) but in turn may improve justification for funding requirements and therefore facilitate budget approval. In other maps, interdepartmental policy alignment and collaboration are seen as levers to optimise the use of funding (map 2, map 8, map 12) (see section 3.2.3).

3.2.3. Governance and legal capacity

Policy alignment and cooperation between governmental departments was mentioned in many interviews as crucial for improving resilience. It was argued that cooperation favours coherent decision making among policy departments, leads to a more effective use of funding as well as to incentives that foster a more responsible use of water resources and assets. The recent LWWP was seen as successful in addressing this issue, because it takes a basin wide perspective for drainage and deliberately set up a board of various governmental authorities that are committed to working together.

Cooperation between governmental departments was deemed important to foster a common understanding of problems and identification of adequate solutions (map 9 – narratives). In this way, synergies and economies of scale may be generated through a more effective use of funding (maps 3, 9, 11, 12). Examples include:

- River desilting by the department for rivers would reduce flooding (map 3) which would provide NI Water with additional discharge capacity into natural water bodies (map 11 - narratives).
- Cooperation between the urban planning and rivers departments to prevent new urban developments in flood risk areas (map 12).
- Appropriate desilting of sewers by road services would reduce maintenance costs for NI Water (map 3).
- The need for integrated (catchment wide) water quality control was identified, especially the recognition of diffuse pollution from agricultural land use (map 11). Sharing the burden with the agriculture sector could release pressure on the utility with a positive impact on water quality compliance (map 9), the environment as well as on human health and wellbeing (map 11).

Policy alignment and collaboration would also facilitate the identification of appropriate incentives for wastewater management as well as negative externalities that can arise from other socio-economic sectors. For example, wastewater services provided to residential users are financed through general taxes. This means that customers may not be aware of the value provided by the services and that there are no explicit stimuli that promote a responsible water consumption. However, although water charges could sensitise customers to an appropriate use of the wastewater system through lower water consumption, it was argued such charges have always been unpopular in Northern Ireland (map 2 – narratives, map 6) (see section 3.2.4).

In addition, many participants identified that political will, resistance to change and civil responsibility are part of more complex societal processes that eventually affect the resilience of the wastewater system. As an example, we illustrate map 6 (Fig. 2) in which such dynamics are made explicit. For instance, legislation developed at higher levels of governance paves the way to social responsibility of individuals on the one hand and to coherent policies within governmental and non-governmental bodies on the other hand (map 6, map 9, map 12). In Northern Ireland the current absence of a functional government (map 2, map 6, map 8) confers little credibility regarding the scope of policy to address the public interest (map 6 - narratives) and this in turn provides little motivation for individuals to change behaviours.

Besides, it was also stressed that NI Water depends on decisions taken at higher political levels: its competitiveness relies on budgets and salary regulations decided by the central government which provides limited autonomy and thus limited space for innovation within the water utility (map 6). Such influences of decisions at higher governance levels also become visible with the “Brexit” process which increases uncertainties about NI Water’s logistical procurement modalities and costs (map 2).

In other maps, participants argued that governance can also be driven by “Individual action”. This may be influenced by a societal context with increased public awareness about the imperatives of protecting natural resources and in which preferences of socially responsible individuals and businesses prevail. In this perspective, the voice of individuals plays a crucial role in striving for policy changes (map 2). A counter-example was illustrated by the challenges of implementing SUDS. Currently, there is no clear assignment of responsibility for their maintenance (map 8). Though SUDS should increase resilience in theory, they may therefore end up introducing new vulnerabilities (map 8) (see section 3.2.7).

3.2.4. Customer behaviour and responsibility

The misuse of sewers was identified as a core vulnerability in Belfast’s wastewater system (map 1, map 11). Blockages are frequent due to inadequate amounts and types of solids in the network such as fats, oils and greases (FOGs) or inappropriate materials the system is not designed to cope with (baby wipes, clothes or kitchen paper). This was mentioned to be caused by a lack of awareness of the general public. The misuse of sewers often leads to in-street or out-of-sewer flooding and to combined sewer overflow discharges that pollute water bodies.

Participants highlighted that in Northern Ireland there are issues of illegal discharges into the sewer network and also directly into the environment. These come either from industries searching to reduce costs or from illegal activities. In Northern Ireland, high electricity costs and taxes do not incentivise industries to discharge wastewater correctly (map 1). Neither does the absence of awareness about the impact of such discharges (map 1, map 2, map 6, map 1, map 11, map 13). Interviewees reckoned that not all hotels or “fast-food” chains would make the effort of legal discharges if more convenient otherwise, even if discharges were free of charge (map 1). In Northern Ireland, there is also illicit diesel produced through a transformation of agricultural diesel. Toxic by-products stemming from this illegal activity are released into the environment or into sewers.

Conversely, it was argued that individual behaviours can also positively influence and promote legal changes through civil

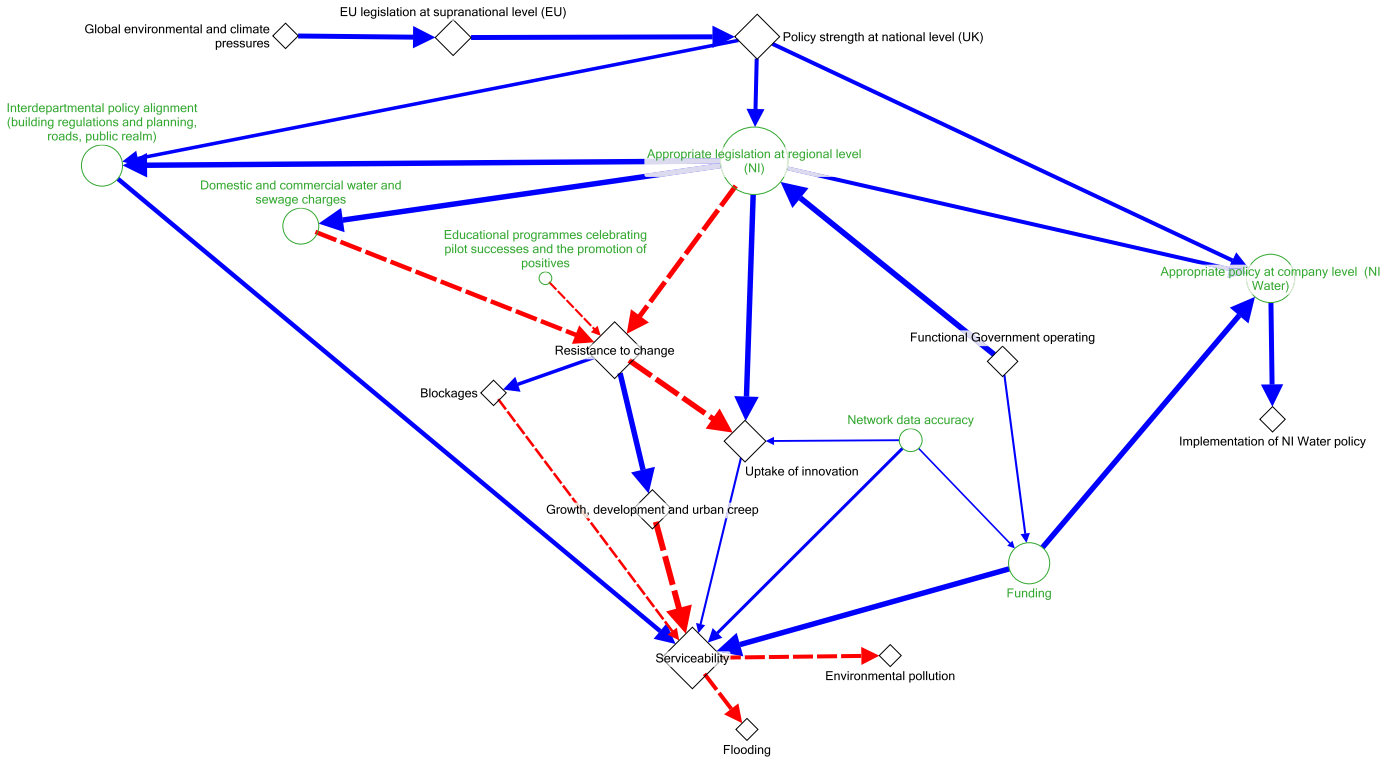

Fig. 2. Resilience map 6 embeds governance and legal capacity in more complex social dynamics. Blue (full) arrows indicate a positive influence (for example, an increase in concept A leads to an increase in concept B) whereas red (dashed) arrows indicate a negative influence (an increase in concept A leads to a decrease in concept B); black diamonds are system concepts related to resilience and vulnerability; green circles indicate elicited interventions to increase resilience. The size of each diamond and circle reflects the centrality which is the sum of the absolute incoming and outgoing connection weights (degree centrality).

engagements, lobbies and the media (map 2) (see section 3.2.3).

3.2.5. Standards and compliance

Tightening of environmental standards were identified as a potential vulnerability for the utility as changes in standards can often occur at a faster pace than the infrastructure upgrades of wastewater facilities. At the same time, population growth and development make it more and more difficult to maintain the required thresholds. The associated increased likelihood of non-compliance can eventually lead to development constraints (map 9) or to legal prosecution of the utility (map 1, map 5, map 15). This leads to a permanent pressure on the utility to keep up with increasing demands (map 13) (see section 3.2.1).

It was observed, that both worsening and improving surface water quality can trigger a tightening of standards. Standards may tighten even if the performance of water utilities in terms of the quality of their final effluent increases, as water companies are expected to further improve on their performance (map 1). This constitutes an unintended consequence for the water utility as, by performing well, it puts further pressure on operations to address increasing expectations. This is especially relevant in a catchment with sensitive water bodies such as Belfast.

3.2.6. Human capital

Continued high quality delivery of wastewater services relies heavily on human capital. With about 30% of NI Water personnel expected to leave the utility in the next ten years, the company faces potential vulnerabilities in terms of human resources (map 4 – narratives and Fig. 3).

According to the interviewees the company needs to prepare for substantial changes. On the one hand, the ageing workforce at NI Water, and a competitive labour market, with high turnover rates among new employees may trigger a loss of skills and knowledge within the company (map 4). This was said to particularly affect the wastewater side of the company as its ageing profile is higher than average. On the other hand, senior workers may become less familiar with new technologies leading to barriers in their implementation and maintenance. In this regard, SUDS are already seen as a barrier for resilience (see section 3.2.7) because they require a different expertise compared to historical drainage infrastructure (map 12).

However, the participants also identified drivers beyond the control of the company. For instance, the “Brexit” process may limit the company’s access to skilled labour (map 2). NI Water is also limited by the public sector pay agreement and decisions at central government reducing leeway to increase the competitiveness of salaries within the company (map 4). Participants provided the example of difficulties in recruiting electricians at NI Water because the company could not offer sufficiently competitive salaries.

Phased retirement policies, training of new and young workers, career development plans and school campaigns to attract students into a diverse employment pool for NI Water were suggested as interventions to address this potential “brain drain” within the utility.

3.2.7. Knowledge and uncertainties

The lack of knowledge and the uncertainties it creates were identified as a fundamental barrier to resilience in the wastewater sector. Map 9 particularly unpacks this theme in more detail.

Participants suggested that uncertainties about local climate change impacts, economic development as well as lack of sewer network data hinder the appropriate assessment of network needs

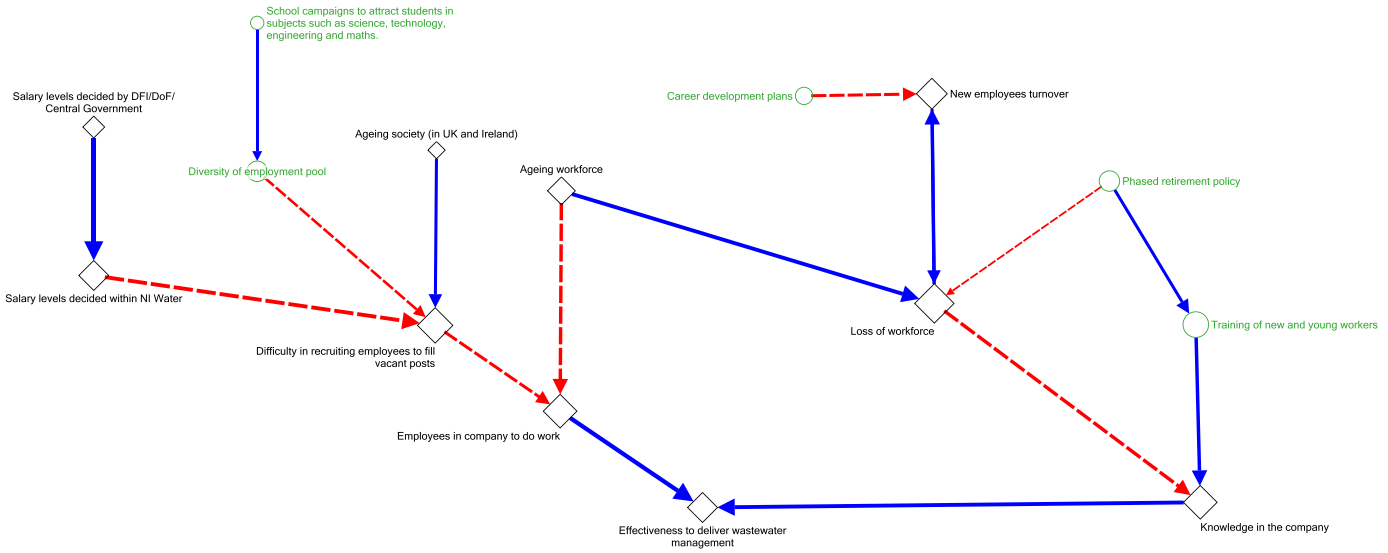

Fig. 3. Resilience map 4 focuses on the human resource aspects of resilience and vulnerabilities. Blue (full) arrows indicate a positive influence (for example, an increase in concept A leads to an increase in concept B) whereas red (dashed) arrows indicate a negative influence (an increase in concept A leads to a decrease in concept B); black diamonds are system concepts related to resilience and vulnerability; green circles indicate elicited interventions to increase resilience. The size of each diamond and circle reflects the centrality which is the sum of the absolute incoming and outgoing connection weights (degree centrality).

(map 9). Participants pointed to trade-offs between drainage and treatment capacity that need to be well understood in order to make optimal investment decisions on storm water separation vs. treatment capacity. If there are higher expenditures on discharge arrangements in the catchment, implying longer outfall and different discharge points, more water can be captured and less water may need to be drained and treated. Conversely, reduced discharge arrangements require to increase drainage- and treatment capacity. However, there are deemed to be insufficient drainage area studies and models that can inform such decisions. This applies also to diffuse pollution: water bodies are polluted not only by wastewater effluents but also by road- and agricultural drainage, thus, accurate knowledge of the sources and pathways of pollution are deemed to be required (map 9, map 11). Uncertainties were also linked to political processes, such as the outcomes of the "Brexit" negotiations (map 2, map 11) (see section 3.2.3).

Ultimately, the lack of information and knowledge can lead to cascading vulnerabilities: inaccurate information may lead to resilience deficiency of solutions entailing for example increased energy consumption, sub-optimal investment decisions (see section 3.2.2), non-compliance with requested water quality standards (see section 3.2.5), lower capacity to cope with exceedance (see section 3.2.1) or a degradation in wellbeing and human health (map 9).

It was argued that in the face of new societal challenges like climate change, innovation uptake is required for resilient solutions (map 6). Yet, technological transition periods are inherently associated with uncertainty. For instance, despite promising results in terms of flood risk reduction, there is currently uncertainty about the effectiveness of SUDS in Northern Ireland (map 8). Given the multitude of typologies and settings of SUDS, these may require a shift in expertise of water utility staff as well as real estate developers - accompanied by increased funds - compared to what has traditionally been done (map 12) (see sections 3.2.3 and 3.2.6).

3.3. Participant feedback

Questions and observations from participants provided insight into some of the methodological issues linked to FCM.

3.3.1. Weighting of connections

One of the most frequent issues raised concerned the quantitative scoring process of FCM. In some instances, the interpretation of the weights was not clear. In such cases the analyst suggested participants to "subjectively define the strength of relationships according to their own experience and knowledge" and provide their rationale as proposed by the interview guidelines (Appendix A1).

In some cases, the weights were interpreted by participants as being dynamic or conditional upon circumstances. In other cases, questions were raised as to whether the weights should reflect the current situation in the Belfast area or what should occur in an ideal case. Participants recognised the subjectivity of the process as well as their imperfect knowledge about specific weights. For example, participants were uncertain about the role of wastewater services for the global attractiveness of the city or the consequences of pollution on human health. Similarly, some interviewees considered the effectiveness of specific interventions to be uncertain, such as the effects of human resource policies within the water utility, policy change at governmental levels or the awareness campaigns to change customers' behaviour.

Different interpretations of scores were also related to the temporal and spatial scales that resilience drivers refer to. For example, while some argue that there is a strong link between wastewater treatment and greenhouse gas emissions, other participants consider the impact negligible because Belfast's wastewater system contributes little to global emissions. The two interpretations reflect different but equally legitimate cognitive reasonings of the participants. There is a priori no reason to discard either of them. Providing the accompanying storylines (Appendix A4) can help in reducing such ambiguities.

3.3.2. Complexity and limitations of FCM structure

The bulk of resilience concepts and connections that were expressed during the interviews could be drawn as networks. In some cases, however, conditionality, dynamics, non-monotonous

relations that were touched upon during interviews could not be mapped, and needed to be reflected in the storylines (Appendix A4).

3.3.3. Consensual and conflicting issues

Within group sessions we did not experience conflicting issues. We attribute this to having nominated the participants together with NI Water senior managers, selecting participants within current working teams. However, when comparing the perspectives across interviews, we identified cases with divergent views. This was observed for example around the issue of who holds the responsibility of water pollution. Depending on the interview this could be the water utility, farming, individual customers, decision-makers within the agricultural department or policy makers at other levels of governance. A second example with conflicting views was the question about the sufficiency of funding or the necessity to better manage granted funds. A third example was the issue about who should be responsible for SUDS implementation.

4. Discussion

In this study we propose a new approach that systematically screens for sources of vulnerability and simultaneously identifies resilience interventions. We believe this approach to be useful as it integrates a wide range of perspectives to identify possible vulnerabilities as well as resilience actions in a wastewater utility that could not be easily detected with purely quantitative methods.

4.1. Complementary views and the value of subjectivity

As from our experience in Belfast, resilience was usually better understood by participants through its vulnerability lens. This suggests that for wastewater practitioners the academic divide between natural sciences (resilience lens) and social sciences (vulnerability lens) actually represents two complementary facets of the same coin. For the wastewater practitioners, resilience was perceived not to be necessarily associated to extreme conditions but to drivers related to daily practice, including for instance governance, human capital and civil responsibility. Failures in these domains may amplify failures of the wastewater system under extreme events.

We here sought to move beyond the different existing definitions of resilience that exist in the literature (Juan-García et al., 2017) and elicit subjective views of what resilience implies for different actors. Eliciting diverse views allows us to capture topics and reveal connections that are not necessarily obtained by single and tightly defined impressions, by consensual perspectives or by quantitative approaches of resilience (Carpenter et al., 2009; Oppenheimer et al., 2007). In such approaches, concepts such as “Political will” and “Civil responsibility” could be difficult to capture. Ultimately, the resulting wide range of resilience perspectives obtained can be used to screen for issues that warrant a more detailed exploration using traditional quantitative assessments based on statistical analysis or phenomenological modelling.

Resilience views are necessarily those of the participating agents. Our outcomes therefore are a reflection of the choice of the interviewees. Thus, it is important to be explicit and transparent about which agents were selected and why (Appendix A2). This selection should be done together with the final beneficiary of the study (for example the senior management of the wastewater utility).

Despite this subjectivity, the approach is open, in that it allows for addition of further participants to include more backgrounds and hierarchical levels.

4.2. Sensing complexity

The approach develops a network view of a complex system. The building blocks are simple cause-to-effect relationships revealed by the reasoning of participants. In this way they are able to develop a complex model which could not be held in the mind in its entirety. Studying such a network provides the possibility to better appreciate how interventions may propagate in unexpected ways and produce feedbacks. By revealing interconnectivity, the methodology can also uncover potential unintended consequences which may be central in determining whether interventions increase resilience globally or whether it improves it in one domain while reducing it in others.

Because of FCM limitations in capturing dynamic, non-monotonous and conditional relations, we propose that the maps should necessarily be evaluated together with the accompanying narratives which provide the rationales for the choices made when drawing the maps.

4.3. Reflectiveness, inclusiveness and integration

We regard this participatory process as leading towards a more “reflective”, “inclusive” and “integrated” view of resilience compared to existing resilience approaches (Table 1). It is reflective and inclusive in that it reflects on experiences and knowledge of a variety of actors. It recognises resilience perspectives across hierarchical levels as equally legitimate to be accounted for. It is also integrated, because it considers wastewater management as part of a more complex urban system in which multiple domains interact. For instance, we find that resilience in the wastewater sector may be strongly influenced by issues in water supply, agriculture and in political and cultural domains which are often underrepresented in technical resilience studies.

4.4. Transferability and flexibility of approach

The flexibility of this approach allows for transferability to other locations, zooming in and out to different levels of detail and aspects of the water system. Importantly, as resilience perspectives are a reflection of the knowledge of participants, the application of our approach to different sites will naturally highlight different dominating themes than those encountered in Belfast.

Thereby, the approach simultaneously addresses the need for a standard framework with the necessity of being case specific, “making possible comparisons between cases” (Juan-García et al., 2017).

By linking sources of vulnerability with drivers of resilience the methodology illustrates perceived relationships between stressors, impacts and interventions which makes it intuitively applicable by practitioners. By doing this, the approach can also be used to operationalise other existing frameworks such as the “safe-to-fail” framework developed by Butler et al. (2016).

4.5. Ancillary benefits and implications for practice

The suggested approach can empower the involved participants to better appreciate the complexity of the system they work in and may improve the communication between departments with different interests and perspectives. In our study both strategic and operation managers mentioned the benefits of such an exercise as the participants reflect on their system in a way they are not accustomed to do.

The results consisting of maps and narratives may be used to inform and initiate discussions between department heads, risk- and asset managers of water utilities as well as their external

partners such as funders, regulators or associated departments (transport, agriculture, energy, etc.). It might prove to be especially useful for studying nexus issues, for instance when addressing complexities at catchment level. It might prove equally beneficial to employ it as a monitoring tool by repeating the screening process periodically with changing agents. We deem this type of exercise to be a useful precursor to the identification of specific issues of concern that may then be studied in more detail with more traditional quantitative methods.

5. Conclusions

Taking a systems perspective, we suggested a new methodology to capture a wide spectrum of different understandings and interpretations of resilience in a wastewater system. In an engagement process with practitioners, cognitive maps were elicited. The methodology reveals major drivers of vulnerability, their propagation mechanisms and identifies resilience measures. We believe that this vulnerability screening approach can support directors, risk- and asset managers of wastewater utilities to identify interventions from an integrated system perspective.

- Our approach facilitated a participatory process that is “reflective” (capturing reflexions of practitioners in a discussion with the analyst), “inclusive” (that includes internal and external participants with diverse responsibilities) and “integrated” (that enables to account for feedbacks to and from other departments of the water utility and in interrelation to larger urban resources and networks, such as legal, social and governance systems).
- The questionnaire used for this assessment can be adapted for studying other issues at different spatial scales, levels of detail and domains in the water sector, for instance, in the context of pollutants of emerging concern.
- This approach may be useful to decision makers for “risk screening”, including the identification of different issues of concern, shared or conflicting points of view, feedbacks to and from other systems, including detecting unintended consequences of measures that may increase resilience in one sector while reducing it in another.
- The methodology with the resulting maps and narratives can be a useful precursor to more quantitative and detailed resilience assessments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This study was undertaken within the European Project ALICE (AcceLerating Innovation in urban wastewater management under Climate changE) under the Marie Sklodowska-Curie Actions, Research and Innovation Staff Exchange 2016 (H2020-MSCA-RISE) number 734560. The research was supported by the Basque Government through the BERC 2018–2021 programme and by the Spanish Ministry of Economy and Competitiveness MINECO through the BC3 María de Maeztu excellence accreditation MDM-2017-0714 as well as the Ramón y Cajal RYC-2013-13628 grant. We would like to express our gratitude to NI Water staff for their invaluable support during the secondments and thank all the professionals who took part in the mapping sessions. We would also like to thank the reviewers for their constructive comments that improved our manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.watres.2020.115780.

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