Emerging pathogens and deliberate attacks on water supplies: A scenario planning workshop

Julii Brainard*, Charlotte C. Hammer, Maha Bouzid, Paul R. Hunter and the Aquavalens Consortium

Norwich Medical School, University of East Anglia
Norwich NR4 7TJ, Norfolk, United Kingdom

*corresponding author: j.brainard@uea.ac.uk

Short Title = Scenario planning for pathogens in and attacks on water

Abstract

Microbiological contamination of drinking water supplies is an ever-present concern for water utility managers. Most such threats are routine, well-recognised and described. Therefore, they can usually be prevented using standard protection measures. Incidents involving emerging pathogens and malicious attacks are inherently less predictable. In a multi-stage process over one day, participants with backgrounds in microbiology, medicine, infrastructure, data analysis, environmental or public health and facility management developed qualitative scenarios on potential threats posed by either an emergent pathogen in or a microbiological attack on drinking water supplies in a European country. Participants were guided via structured activities to identify key factors that would impact the magnitude and severity of such an emergency. Plausible variant states for each key factor were determined, and participants constructed sequences of events to create scenario outlines. Five scenarios in outline form are reported which incorporate genuine future events as well as pathogens of international concern. Common features that would exacerbate all scenarios were: under-investment in public services, inadequate water quality testing and monitoring and lack of resources to keep water supplies safe. Participant evaluation of their scenario planning experience was broadly very positive and the scenario planning process was received as credible and relevant.

Keywords: scenario planning, water safety, emerging diseases, contamination, health protection

Introduction and aims

The prospect of microbiological contamination of drinking water supplies is an ever-present concern for managers of public water supplies. Most such threats are routine, well-recognised and described, and thus can usually be prevented using standard protection measures. Incidents involving emerging pathogens and attacks, however, are inherently less predictable. Either because by definition emerging pathogens are not well understood, or because of deliberate planning by attackers to hide their actions and maximise surprise. Vulnerability of municipal water supplies to such events is a topic of ongoing concern. (Haimes *et al.* 1998, Clark & Deininger 2000, Qiao *et al.* 2007, Gleick & Heberger 2014, Mutchek & Williams 2014). Documented plots to deliberately contaminate drinking water supplies in the period 1946-2015 were described by Brainard and Hunter (2016). Literature about emerging diseases in drinking water is more expansive and diverse and tends to be segregated by species, groups of similar microbes or parasites, outbreak context or types of control methods. For instance, a worldwide review of protozoa outbreaks is in Baldursson and Karanis (2011). Sinclair *et al.* (2009) undertook a structured literature review to search for and report on virus-disease outbreaks in recreational waters.

Emerging diseases (ED) refer to poorly understood, often relatively recently discovered pathogens for which our understanding of the risks posed to public health through environmental routes of transmission are not well understood. Concerns about ED and potential mitigation measures overlap greatly with concerns about and possible strategies to resist deliberate contamination of water supplies (such as for terrorist reasons). This report documents the methods and outcomes from a meeting designed to help prepare for both possible threats.

Scenarios have been described as “Stories that can help us recognise and adapt to changing aspects of our present environment. They form a method for articulating the different pathways that might exist and identify plausible steps to move down each of those possible paths“ (Schwartz 1996). Scenario planning can have a positive impact on decision quality in response to uncertain and rapidly developing situations (Meissner & Wulf 2013). Scenario development is the first step towards identifying strategies that result in robust decision making in multi-faceted situations with high uncertainty about possible risks (Kwakkel *et al.* 2016). As part of the exercise, our participants learned many concepts typically involved in structured approaches to scenario construction. Drawing on methods used in other published scenario building events, our approach was pragmatic and adapted so as to be completed in one day and potentially easily replicated in participants' own organisations and workplaces, if desired.

Methods

European professionals with expertise in water safety, water provision, water-borne diseases and envirionmental protection were invited to attend a workshop that was designed to create an active participatory meeting. The workshop format was a short plenary session followed by smaller group collaborative work (in parallel), with a final plenary session at the end of the afternoon. All participants were allocated to either the Emerging Diseases (ED) or Attack (AtK) groups by event organisers. A subject expert was purposefully placed in each group (acting as both participant and topic expert), in case of technical queries that the facilitators could not answer. Our sessions were normative-participatory in nature, which means they consolidated multiple theories and concepts for participant engagement (Steinmüller 1997).

Theoretical foundation

Scenarios are "hypothetical sequence[s] of events constructed for the purpose of focusing attention on causal processes and decision points" (Kahn & Wiener 1967). Thus, scenarios are hypothetical but still outlined and concrete (Wilson 1978). Scenario planning is suited to developing multiple alternatives of possible futures taking into consideration unlikely futures with unknown probability of actually occurring. These are relatively extreme events, so-called very rarely expected 'Black Swans'. Alternative scenarios can be used to explore possible tipping points and thus interventions that might disrupt multiple negative scenarios. Because the scenarios we sought to develop were anticipatory in nature, we used a participatory-normative approach to scenario planning. There is little to no formalisation in this type of scenario planning unlike in forecasting and trend exploration (Steinmüller 1997).

Given the short time-frame, our scenarios were brief outlines, rather than fully developed and written versions. They were semi-global, taking into consideration wider contextual issues but remaining close to the original topic. The scenarios were fully qualitative. We used an intentional interpretation of the scenario, which assumes that the scenario is not the text developed by the participants but rather the blueprint of the future developed by them.

Core concepts

- Key factors and key factor analysis: **Key factors** are those factors that define the outcome of an event. They need to be highly important (i.e. must have strong impact) and uncertain (i.e. not definite, such as the force of gravity on Earth).
- **Silent sorting**: applicable at stage of nomination and grouping of possible key factors. The process is done in silence to encourage multiplicity of perspectives.
- Key factor variants: A **variant** of a key factor is a variable status that the factor could take (i.e. if a key factor is climate, variants could be hot and dry, cold and wet, cold and dry, etc.)
- Backcasting: **Backcasting** is the process to link the (future) scenario with the present. Backcasting starts at the point of the scenario (in our case 2023) and describes events in reverse order, going backwards from future to the present. It is the opposite of forecasting and seeks to develop pivotal points that lead to a scenario becoming reality or not.

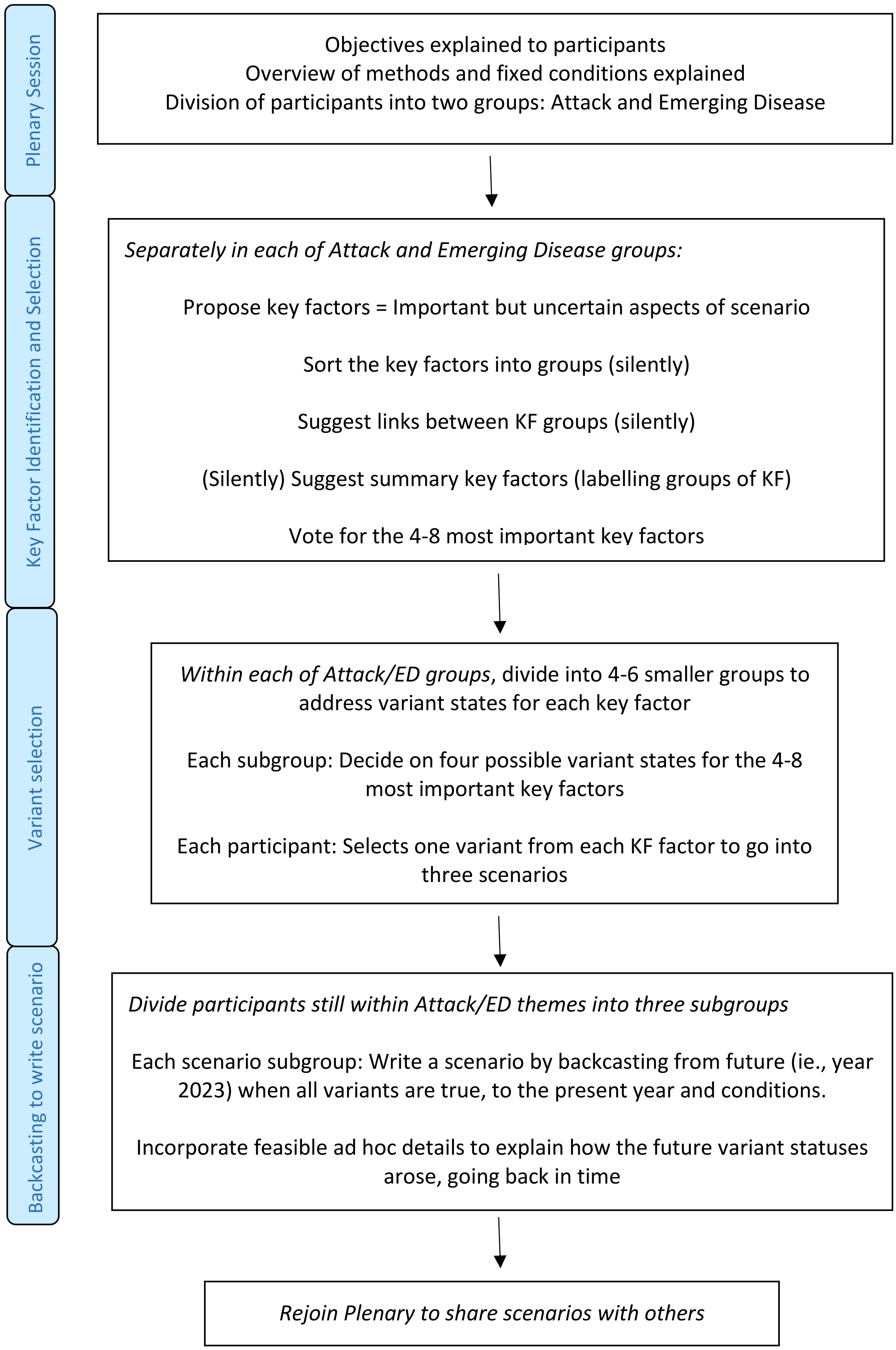
Implementation

Prior to the workshop, fixed conditions for each scenario were decided by the facilitators. These fixed conditions are parameters that cannot be changed during the scenario planning process, and serve to orient the outputs towards prespecified objectives. Fixed scenario conditions are listed in Table 1. Figure 1 summarises the steps that participants went through during the workshop.

Table 1 | Fixed conditions for building each scenario

Both Scenarios	
Included conditions	Year = 2023, In a water supply that participants are responsible for. Within European area. Pathogen is unknown initially.
Excluded possible factors	Any problem more important than whether the water is safe to drink, such as concurrent nuclear war, plague-like disease, zombie apocalypse, etc. At discretion of facilitator.
Respective scenario fixed conditions	
Emerging disease	Presence in water is not result of deliberate contamination Has been linked to some deaths.
Attack	Deliberate attack confirmed by evidence of break-in, intelligence chatter, and linked hospital admissions.

Figure 1 | Scenario Planning Workshop Methods



Identification and prioritisation of key factors

For the workshop, we devised an approach that allowed scenarios to be devised quickly (work progressed from factor identification to simple scenario descriptions in one full working day). Participants were randomly allocated to one of the two scenario groups (attack and emerging pathogen) with some adjustment made to ensure relatively equal distribution of skills and representatives from the same organisation(s). Within each group, participants were asked to identify all relevant key factors that are likely to influence the scenario they are working on. These were written on adhesive notes and stuck to a wall or whiteboard. Duplicate entries were removed and the participants were asked to check if they could think of any further key factors. Once all key factors were identified and agreed, participants were asked to look for relationships and interactions between these factors, with the option of creating groups, over-arching category labels, and relationship indicators such as arrows (Figure 2). Participants were allowed to nominate, remove, cluster or remove from clusters both their own key factors and those contributed by other participants. This was done in silence (silent sorting). Any arguments about the validity of a factor or its associations had to be resolved silently by moving or removing the respective factor. Silence deterred habitual deference to verbally or personality dominant colleagues and meant that minority voices and alternative perspectives were more likely to be heard.

The previous phase allowed the development of a complex network of interrelated key factors. The next stage was to identify the most important factors for each scenario. In the voting stage, each participant was asked to label what, in their opinion, were the four most important factors. The labels could be applied to a single factor or any combination of factors. A participant could also give all their votes to the same single factor, if they felt very strongly about it. The factors with the most votes were selected for the next step, which was generating variant states for each factor. A repeat round of voting was an option in the event of tied votes.

Factor variants

For each key factor selected, participants were asked to identify four plausible variant states. This was done in small groups (3-4 people). Examples were given so as to clarify the process. For instance, if disease transmission is a key factor, examples of variant states could be: very infectious, not very infectious, waterborne or transmitted by bodily fluids.

Figure 2 | Output of silent sorting, clusters of potential key risk factors, with summary topics for each group and results of voting (dot stickers) for the most important key factors.

Scenario building

After variants were devised, simple scenario building was demonstrated to participants. This was done by going person to person, with each person choosing one variant for each factor, making sure that the variants selected could plausibly happen together. After each variant was chosen, that same variant was not available for the other scenarios. Once all factor variants were chosen, they were combined to form a 'skeleton' for each scenario. Subsequently, small groups (4-6 persons) worked on backcasting for their specific scenario, starting in the projected year (2023) and working backwards to fill in the story of how the scenario might happen from our starting point in late 2017.

Participants' feedback

A feedback questionnaire was distributed to the participants to assess their opinions about the scenario planning workshop (Appendix 1).

Results

Participants

Thirty-one participants attended the workshop event in Barcelona, Spain, held on 7 November 2017. They had expertise in microbiology, medicine, infrastructure, data analysis, environmental and/or public health and facility management. Most worked for water companies, universities or government agencies. Most were professionally based in Spain, but there were participants concurrently working in seven other countries: Austria, Denmark, France, Netherlands, Norway, Portugal and UK. Fifteen experts were placed in the emerging pathogen group, and sixteen in the attack group.

Factors and variants

The key factors and variants chosen by the participants for the emerging pathogen (ED) and attack (AtK) scenarios are shown in Tables 2 and 3, respectively. The ED group identified eight key factors, while the AtK group identified five. For each key factor, four variants were successfully formulated. Three key factors were shared between the two scenarios, namely emergency response, communications and pathogen characteristics/ source. Interestingly, the scope of these factors was described somewhat differently between the two groups, which is very much allowed within scenario planning methods. The ED group members were quite concerned with pathogen characteristics (infectious dose and inactivation methods) and modes of transmission, while the AtK group considered pathogen characteristics as a mix of pathogen types. One variant for source of pathogen (variant 4) included infectious dose, persistence and incubation period. Similarly, communication strategies identified by the ED group were multi-faceted and revolved around the efficacy of a potential crisis committee, interaction with media and political influences. Conversely, the AtK group described only the outcome of whatever communication efforts were in place. The key factor variants were poor, perfect, disastrous, etc. This was also the case for the key factor emergency response. The AtK group derived variants such as none, incomplete and complete. The ED group categorised the emergency response and defined three key areas: health systems, official communication and compliance. All three components were considered while deriving variants (Table 2 and 3). The AtK group considered access to healthcare as a stand-alone key factor. Finally, the AtK group identified areas that were exposed to the contaminated water as a key factor. This is particularly relevant considering the uncertainties about the scale of the malicious attack.

Outline Scenarios

When building the scenarios, one group found scenario construction too difficult; they were inclined to think that detection methods (genomic analysis, specifically) made their scenario too unlikely to happen. However, five of the scenarios (two emerging disease and three attack) were well enough developed to be reported here. It was commonly mentioned in all scenarios that lack of resources or policy changes that led to poor equipment maintenance or substandard monitoring of contamination or other reduced microbe control measures could considerably exacerbate the worst impacts of any threat scenario. All scenarios had to make plausible assumptions about decisions and policies adopted by health systems, governments and others. Policy changes could be to reduce frequency of testing, remove types of testing, remove chlorine from water. Some of the suggested details in all of the scenarios are sensitive, especially the specific mechanics of how an attack could happen. For this reason, and for brevity, we publish here only the timelines for each scenario, which start five years in the future and work backwards to present day. The variants used to build each scenario are listed in Boxes (1a-5a). Corresponding scenario timelines are listed in Boxes (1b-5b).

Evaluation

26/31 (84%) individuals returned completed questionnaires to the organisers. Feedback was broadly very positive (see Table 4).

Table 2 | Factors and variants chosen and for the emerging diseases scenarios

Key Factor	Variant 1	Variant 2	Variant 3	Variant 4
Attack rate (AR), Morbidity (Mb) and Mortality (Mt)	AR: Just the already ill, young, very old Mb: Only a few people who are sick will have severe illness Mt: no fatalities, diseases treatable	AR: medium transmission 1/10,000 gets ill Mb: Symptoms more severe but not lethal; care at home possible Mt: Folk w/ weak immune systems most at risk	AR: disease is communicable; requires quarantine Mb: Symptoms are severe, infected need monitoring & treatment Mt: higher mortality rate, 1/1000 infected will die	AR: high transmission rate Mb: Symptoms are very severe, fast progression Mt: Risk of death increases if no treatment within 72 hours
Emergency response	Health systems (HS) can cope with # infected, official communications are efficient, poor compliance expected	HS cannot cope with demand, official communications are effective, expect good compliance with instructions	HS are coping, official communications not effective, people expected to comply with instructions	High demand on HS, official communications will be very forceful, people are expected to have poor compliance
Transmission	Waterborne only	Waterborne spread & person to person	Airborne & person to person & waterborne spread	Varies due to seasons or vulnerability of individuals
Identification of outbreak and source	Source identified, containable as route is known	Source identified, but cannot be contained (route unknown)	Cannot identify source, situation can be contained	Source cannot be identified, route unknown, no containment
Communica-tions	Crisis committee is organized with designated spokesperson, good liaison with political institutions and press	Crisis committee is organized with designated spokesperson, there is supervision of media and political influences, press conferences occur	Crisis committee is organized with designated spokesperson but no social media and official communication via radio or TV	No crisis committee is organized, so no spokesperson or monitoring / interaction with social media or press
Human resources and contingency plan	Both Available and skilled	Both available but lack skills	Resources and skills available, no contingency plan	No resources (e.g., on strike), no contingency plan, lack of skills
Analytical technologies	Fast, cheap, standardized and specific	Fast, expensive, specific, not standardized	Cheap, specific, slow, not standardized	None available but other AT could be adapted
Characteris-tics of pathogen	Low infectious dose, inactivated by chlorination	Low infectious dose, not inactivated by chlorination	High infectious dose, inactivated by chlorination	High infectious dose, not inactivated by chlorination

Table 3 | Factors and variants chosen for the attack scenario

Key Factor	Variant 1	Variant 2	Variant 3	Variant 4
Inter-agency cooperation (emergency response plans)	None	Incomplete	Complete, but personnel not trained	Complete & personnel trained
Source of pathogen	Mix of pathogens	Virus eradicated or uncommon in Europe	Not detected by normal control systems	Highly infective low dose, persistent in water, long incubation period
Areas Water Reached	Small area, high impact, chlorinated, reticulated network	City wide, medium impact, 30% not chlorinated, reticulated	1 house, high impact, not chlorinated, branched network	City wide, medium impact, chlorinated, branched network
Communications Strategy/ Management of General Public	Perfect communications in every way	Complete Disaster in all ways	Good message, but at wrong people	Poor targeting led to unnecessary public scare, total chaos
Access to healthcare	Hospitals shutting down due to contamination, staff and /or shortages, complications	Public access hindered due to many factors	Hospitals are overcrowded	Violence or panic inside and around hospital

Box 1a | Variants used to construct scenario described in Box 1b

(Attack rate, morbidity, mortality) AR: Only vulnerable groups are susceptible (young, very old); Mb: Only a few people will have severe sickness; Mt: no fatalities expected, disease is treatable

(Emergency Response) Health systems cannot cope with demand, official communications are effective, can expect good public compliance with instructions

(Transmission) Varies due to season and vulnerability of individuals

(Identification of outbreak and source) Source identified, but cannot be contained as route unknown

(Communications) Crisis committee is organised. There is a designated spokesperson but no social media or official media communication via TV, radio, printed press

(Human resources) None (eg., due to strikes), plus no contingency plan, lack of skilled personnel

(Analytical technologies) AT are cheap, but not standardised, are time consuming, are specific

(Characteristics of pathogen) Low infectious dose, inactivated by chlorination

Box 1b | Emerging disease scenario (1)

Olympic Games Paris 2024

- 2023: Outbreak in France (1 year before the games) affecting persons already ill, limited severity and no fatalities. Pathogen: low infectious dose but inactivated by Chlorine
- 2022: Because of the Games, French government increases recreational areas with water fountains, playgrounds, more public drinking water fountains
- 2021: Summer with high temperatures, linked to increasing pollution after US pulled out of Paris Climate Change Convention
- 2020: EU allows decrease in Chlorine levels, French water supplies go Chlorine-free
- 2019: EU stops investing in new water safety tools and nobody is submitting related proposals, strikes because of low salaries, tax increases and pension age increase lead to health systems becoming vulnerable and no supervision of social media or official social media strategy
- 2018: Launches of new platforms and tools for rapid monitoring & pathogen detection but health authorities only recognise traditional/conventional methods -> new tools are not recognised as gold standard

Box 2a | Variants used to construct scenario described in Box 2b

(Attack rate, morbidity, mortality) AR: High transmission rate; Mb: Symptoms are very severe, fast progression; Mt: Risk of death increases if no treatment within 72 h

(Emergency Response) High demand on health services, official communications are very forceful, people are expected to have poor compliance

(Transmission) Airborne and person to person and waterborne

(Identification of outbreak and source) Cannot identify, but can be contained

(Communications) Organised crisis committee has designated, spokesperson official who answers to social media and there is agreement among political institutions who are included in the crisis committee. There are official communications with the press

(Human resources) There are resources available, contingency plan available, skills are available

(Analytical technologies) None suitable for pathogen, but other AT could be adapted

(Characteristics of pathogen) High infectious dose required, is NOT inactivated by chlorination

Box 2b | Emerging disease scenario (2)

Everywhere Unknown

- 2023: Large outbreak across EU produced by an Unknown microbe that is transmitted by air, person to person, waterborne. Infection dose is high but microbe is resistant to chlorine.

- 2022: Repairs are completed that happened after the 2021 overflows, to infrastructure for drinking water and waste water. However, this meant large investments that diverted resources away from research and development.

- 2021: Big overflows overwhelm drinking and waste water infrastructure (causing huge damage); concurrent critical economic situation.

- 2019; Crisis committee identified the problem (partly) and communicated to public health agencies how they should treat future cases.

- 2017: Sporadic cases of an unknown opportunistic microbe, virulence of which depends on environmental conditions (unknown).

Box 3a | Variants used to construct scenario described in Box 3b

(Inter-agency cooperation and emergency response plans) Complete, but personnel not trained

(Source of pathogen) Not detected by normal control systems

(Areas of water reached) City wide, medium impact, chlorinated and branched network

(Communications strategy & management of general public) Perfect communications in every way

(Access to Health Care) Hospitals are overcrowded

Box 3b | Attack scenario (3)

Disgruntled Employee

- 2023: City-wide outbreak with medium impact not detected by normal control systems during especially severe flu season which is overcrowding hospitals. However, there is good communication and a complete response plan (despite the lack of trained personnel)
- 2023: Bad guy makes attack plan, does not want to kill but expose company as unready. Gets pathogen from black market source.
- 2022: Bad guy gets fired from water supply Company
- 2020: New detection kits become available and are incorporated into response plans, no resources to train personnel with new kits
- 2017: Water supply company realises that traditional communications are no longer valid and make new plans using newer communications media

Box 4a | Variants used to construct scenario in Box 4b

(Inter-agency cooperation and emergency response plans) Incomplete inter-agency co-operation

(Source of pathogen) Mix of pathogens

(Areas of water reached) Small area, high impact, chlorinated, reticulated

(Communications strategy & management of general public) Complete disaster

(Access to Health Care) Hospitals are shutting down due to complications from staff shortages

Box 4b | Attack scenario (4)

Dystopia 2023

- 2023: Unknown actors contaminate water supply to the National Assembly building and surrounding area, using multiple different pathogens some of which are hard to identify. Appears politically motivated. Response is poorly managed with different agencies not co-operating. Inter-agency co-operation break-down because Health Dept. does not want to reveal internally known weaknesses in staffing levels. Security services (civil protection) didn't communicate the known risk to the water system to avoid revealing weaknesses in their system and their capabilities. There is high degree of inter-service rivalry in the background exasperated by a recent funding crisis. Multiple conflicting messages are sent by each agency to the media by different services to try to make their agency visible to the public. The mix of pathogens suggests this attack is backed by a highly sophisticated sponsor (could be State or well-resourced internal opposition). This sponsor sows additional confusion by using other assets to spread misinformation online

- Late 2022: Budget crisis due to lack of political direction and divided National Assembly

- Early 2022: Victorious political party is mired in corruption scandals left over from the election and does not command a majority. Money seems to be going missing or is not spent effectively. Public services (hospitals and public health in particular) are being shut down or reduced in services they offer due to lack of money

- Late 2021: Disputed and acrimonious election with many claims of corruption. Very little trust in politicians. Some indications of external interference in the elections

- Early 2021: Government falls following release of emails from parliamentary systems showing high levels of misbehaviour in public office (fiscal and other)

- Late 2020: Corrosive atmosphere to public; each political party seems to only represent narrow interests

- 2019: Increasing polarisation in the media. Increasing effect of "filter bubbles" in people's online life. Increasing intolerance of views different to one's own. Attempts to rewrite history by removal of public monuments and statues

Box 5a | Variants used to construct scenario described in Box 5b

(Inter-agency cooperation and emergency response plans) None

(Source of pathogen) Virus eradicated or uncommon in Europe

(Areas of water reached) City wide, medium impact, 30% of supply not chlorinated, reticulated

(Communications strategy & management of general public) Poor targeting leading to unnecessary public scare, total chaos

(Access to Health Care) Violence or panic inside and around hospital

Box 5b | Attack scenario (5)

Ebola in Europe

- 2023: Attack on water supplies (Ebola virus injected into storage tanks) in large city in target European country. There is chaos with public panic, widespread misinformation about risks, impacts and safety measures that public can take.
- Late 2022: West African terrorists invite and help middle Eastern terrorists to collect and concentrate Ebola virus from faeces (suicide missions)
- Early 2022: Large Ebola outbreak starts in populous West African country
- 2018-2023: Debt crisis, cut in public services in target country. Leads to poor quality hospital services and few resources to maintain good quality public communications. Emergency response plans forgotten or abandoned or become very out of date. Capital investment in protecting and maintaining water supply network is especially badly affected, in large European city (or cities).

Table 4 | Results of feedback questionnaire

Criteria	Results
This workshop was relevant to my needs	81% agreed or strongly agreed
This workshop met my expectations	70% agreed or strongly agreed
This workshop helped me understand scenario planning better	97% agreed or strongly agreed
I enjoyed this workshop and I am glad I came to it	100% agreed or strongly agreed
I understood what to do in each phase of today's workshop, I didn't feel confused.	31% agreed or strongly agreed (46% unsure)
The content was well-organised	84% agreed or strongly agreed
The workshop has made me think about unusual risks in a helpful way	80% agreed or strongly agreed (20% unsure)
This workshop identified risk factors I never thought of before	50% agreed or strongly agreed (46% unsure)
The workshop made me feel better able to prepare for future unusual events	50% agreed or strongly agreed (42% unsure)
I could adapt these scenario methods to use in my own organization.	76% agreed or strongly agreed (20% unsure)
This workshop helped me see how to reduce possible impacts or better manage relevant risks at work	46% agreed or strongly agreed (42% unsure)

Discussion

We describe a set of procedures for running a one-day workshop to facilitate experts to envision a range of plausible scenarios that could threaten water supplies they are tasked to protect. Although the threats poised here were purely biological, the methods could easily be adapted to consider other hazards, such as chemical or radiological threats. Readers can judge for themselves if a similar workshop would be valuable to run within their organisation. The workshop steps described here are not definitively the best way to undertake such a workshop; we describe ways to improve the implementation below. Neither were our resulting scenarios definitive; a different set of experts probably would have identified somewhat different key factors and developed possibly quite different scenarios. The choices of key factors and how participants imagined scenarios was heavily influenced by their own backgrounds (and therefore could be very country-specific). Nevertheless, we hope that our account and comments about implementation may be useful to others pondering whether to run similar planning exercises within their own organisations, in order to inform local risk assessment. Some of our observations described below seem likely to be very generalizable to many settings, with regard to protecting water supplies. A valuable outcome of scenario planning exercises like ours is going beyond worst and best case scenarios; looking for extremes is prone to strong human biases. There are an infinite number of scenarios for any one topic, and scenarios need to be adaptable to local conditions in order to be credible and not just very unlikely extremes. The intermediate steps in the methods we describe can also be a constructive exercise for those involved in water protection, such as identifying key factors (inherently important and uncertain), and the use of silent decision making (the silent sorting methods which encourage the widest range of views to emerge).

Real world implications

Participants found it difficult to plausibly imagine these scenarios except in an environment where protection measures and communications strategies were significantly inadequate. This is encouraging as it suggests an inverse situation is true in the group opinion: the scenarios were very unlikely as long as regulatory standards remain high, and monitoring and accountability mechanisms are well-resourced. Some of the participants with microbiology backgrounds felt strongly that genomic analysis would ensure very rapid identification of pathogen characteristics, so much so that delay in identification or difficulties in planning a management strategy would be negligible. Developments in genomic methods may indeed facilitate quicker removal from water supplies. However, the converse is also true. In an environment with inadequate safety controls, insufficient laboratory methods, poor resources or monitoring, the participants easily imagined a high diversity of ways that an emerging disease or attack could be highly disruptive to provision of safe drinking water in Europe.

Among the many policy changes that could increase likelihood of an emerging pathogen or successful attack were: declines in capital investment, delays in repairing infrastructure, prioritising other public services or promoting public preferences (such as having less chlorine taste in drinking water), as well as reduced intra-agency cooperation. The participants thought such policy changes were unlikely but not impossible, especially given the ever-present pressure on public services to be cost-effective. Policies that would reduce negative scenario impacts were to maintain effective communications with the public and between relevant agencies, as well as well-defined strategies to make water quality testing easier, quicker, more specific and yet still cost-effective.

Event Implementation

The facilitators see many ways that the methods could have been concisely and clearly better explained. We were not prepared for how systematically and thoroughly the participants wanted to approach the task of choosing variants: we should have been firmer about insisting that they think of variants in concise terms. Many participants tried to devise elaborate scenarios as backstories for a possible variant, before they could decide on each variant option. It is certainly possible to dedicate an entire day to decide on factor variants, but for the purposes of scenario building in a one-day workshop, the variants only needed to be possible, rather than especially plausible. The time spent developing and identifying possible backstory details for the variants was still productive, ultimately, because these details were useful when fleshing out details during the scenario building stage.

Operational perspectives

In plenary discussion afterwards, attendees raised further observations about testing regimes. They commented that current methods for water quality testing are well suited for the required regulatory monitoring. However, deference to regulatory standards somewhat acts as a deterrent to trying new or more sensitive testing methods; since the new methods wouldn't be required and may represent an unnecessary and unreimbursed cost. There are also problems with accepting results from new techniques because of their lack of correspondence with data accumulated from conventional monitoring. Some methods are associated with different error patterns (such as higher numbers of false positives), and thus require sensitive decision making with regard to when an alert truly needed to be raised.

The regulatory sector should be receptive to new methods, but getting new methods into practice is often a slow process because of conservationism in the sector. Additional limitations are the usually high cost of newly developed methods. Therefore, the participants agreed that a distinction should be made between regulatory compliance and operational monitoring. It was suggested that a first step in operational implementation is event monitoring. This has been trialled since late 2017 in Spain (Brainard *et al.* 2018).

Relatively new technologies such as whole genome sequencing for typing and source tracking are relevant. These techniques offer value in outbreak investigation for tracing sources of contamination but are unlikely to be unsuitable for routine application in environmental sampling, as the large amounts of data generated could not necessarily be linked to health risks in humans. Microbial source tracking and whole genome sequencing techniques have been developed (Hjelmsø *et al.* 2017) which may be very valuable in bioterrorist attack investigations. Water quality testing strategies can be most protective when implemented in a tiered approach, such that test results are enhanced by complementary information from multiple sources (Rickert *et al.* 2014, Ryzinska-Paier *et al.* 2014).

Limitations

As observed previously, the key factors and scenarios identified by our participants cannot be definitive and may not all be generalizable, instead they are the products of the procedures as described. With regard to our procedures, we have tried to explain them clearly and be candid about what could be improved. We did not subject the workshop or the outputs to a rigorous evaluation scheme. Checklists for evaluating quality of participatory scenario planning exercises are not well-developed, but many resources exist from which such a checklist could be derived, some of which are contextualised with regard to water safety. Acosta Tellez (2014) describes different scenario planning approaches and their strengths and weaknesses when assessed against many evaluation criteria. Scott *et al.* (2012) described how scenario planning must identifying important but uncertain factors, their impacts and ultimately key adaptations to reduce risks of harm. Both Mott Lacroix *et al.* (2015) and Van der Merwe (2008) advocated that scenario planning exercises should produce outputs that are challenging, relevant and plausible; we believe that our scenario planning had many if not all of these attributes.

Conclusions

The scenario building workshop fostered increased awareness of possible risks to water supplies. The methods comprise a process that has credibility for participants by creating a multiplicity of considered perspectives in the process of identifying what are the key uncertain and important factors, and their possible variant states, that could have a high impact on the proposed problem situation. This meeting encouraged health and industry experts to identify vulnerabilities and novel pathways for an emerging disease or attack to threaten water supplies. Very positive feedback about the experience was received, even among those participants who found their scenario was very unlikely. Scenario building could be used to inform Water Safety Plans (Bridle *et al.* 2014, Ryzinska-

Paier *et al.* 2014, Gunnarsdottir *et al.* 2016, Gunnarsdottir *et al.* 2017) for better risk assessment and to improve protection of public water supplies.

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APPENDIX 1

Evaluation Form

Please complete the evaluation for today's workshop – your feedback is valuable.

Topic = ☐ ***Emerging Infectious Disease*** ☐ **Deliberate Attack**

You do not need to write your name on this form, we want your honest opinions. Please tick how much you agree or not.

Criteria	**Strongly Agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly Disagree**
This Workshop was relevant to my needs					
This workshop met my expectations					
This workshop helped me understand scenario planning better					
I enjoyed this workshop and I am glad I came to it					
I understood what to do in each phase of today's workshop, I didn't feel confused.					
The content was well-organised					
The workshop has made me think about unusual risks in a helpful way					
This workshop identified risk factors I never thought of before					
The workshop made me feel better able to prepare for future unusual events					
I could adapt these scenario methods to use in my own organization.					
This workshop helped me see how to reduce possible impacts or better manage relevant risks at work					

Do you have any other comments, such as what could we have improved, or what did you especially like today?

We will NOT share any identifying information about you. Nor will we publish explicit details of the risk factor variants that were identified in today's workshop. However, for evaluation and research purposes, do you consent for your anonymous replies on this form and other anonymous contributions to this workshop that are not useful to would-be attackers, to be shared more widely, with UEA researchers, our research partners and others? (please delete any category that you do not want to have access to your feedback and contributions):

Yes No