Crafting futures together: scenarios for water infrastructure asset management in a context of global change

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ABSTRACT

Drinking water supply networks play an essential role in protecting the human and economic wellbeing of the territories they serve. To ensure continued quality of service, organisations involved in water infrastructure asset management (WIAM) need to deal with a number of issues related to global change. This paper presents the results of an original interdisciplinary foresight approach carried out by a group of engineering and social scientists, in partnership with a number of stakeholders. The purpose was to examine various possible pathways for the future of a French territory. The full title of our foresight study is: 'Supplying water destined for human consumption in Nouvelle-Aquitaine (France) up until 2070'. Four scenarios, as contrasted as possible, were designed based on five components: organisation and operation of the water supply service, social demands in terms of drinking water, the governance context, territorial dynamics, and the overall context. We then ran further simulations to visualise what a given infrastructure network would look like under each set of assumptions, and under different territorial configurations. One significant advantage of our foresight approach is the educational value it has for stakeholders and water managers. Foresight makes the future potentially visible and provides an opportunity to discuss it, in order to able to inform decision-making.

Key words | global change, participative foresight approach, performance of the drinking water service, water infrastructures asset management (WIAM)

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HIGHLIGHTS

- We present an original interdisciplinary foresight approach.
- Our topic is: 'Supplying water destined for human consumption in Nouvelle-Aquitaine (France) up until 2070'.
- Four scenarios, as contrasted as possible, were designed and translated into possible developments and requirements in the infrastructure.
- The aim is to support policy makers and WIAM organisations in assessing their preparedness in the face of global change.

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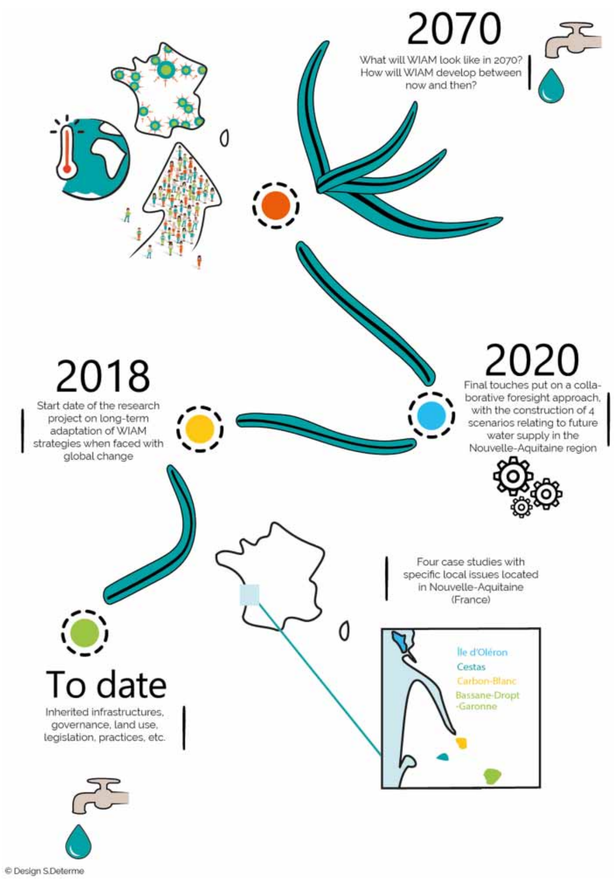
GRAPHICAL ABSTRACT



INTRODUCTION

Drinking water supply networks play an essential role in protecting the human and economic wellbeing of the territories they serve. To ensure continued quality of service, organisations involved in Water Infrastructure Asset Management (WIAM) need to deal with a raft of different issues. These include the following:

- The growing influence of climate and global change (e.g. metropolisation and mobility) on drinking water resources (IPCC 2014, 2018; Vijay *et al.* 2014). Climate change can affect both the availability and quality of water (and thus the reliability of the drinking water supply), due to increasing temperatures, contamination, and other phenomena (Le Treut 2013; AcclimaTerra 2018; IPCC 2018). Climate and global change also have an effect on lifestyle conditions and sensemaking (Vanderlinden *et al.* 2020). Exceptional climatic events such as heatwaves can lead to significant spikes in water consumption (Zuo *et al.* 2015).
- Growing demand from 'user-client-citizens' (Bouleau *et al.* 2011) for increased transparency, solidarity, and justice in the way drinking water supply services are operated. Bottom-up framing and community approaches are increasingly being promoted in the development of new tools to monitor and evaluate water services (García *et al.* 2014).
- The capacity of local authorities and decision-makers to deal with uncertainty and variability when making

long-term investment decisions in water infrastructures. WIAM takes the path of adaptive governance, supporting bioregional approaches and policy experimentation (Huitema *et al.* 2009; García *et al.* 2014). For example, in France, the new regional institutional framework (MAPTAM and NOTRe laws) significantly changes local governance, and emphasises the interdependencies between those issues (Barbier & Roussary 2016; Barone *et al.* 2018).

This fluid and ever-changing context gives rise to a number of questions: What effect does global change have on WIAM? How do issues of global change impact the design of drinking water supply networks and the way in which performance is evaluated? How best can WIAM procedures be equipped to deal effectively with the impact of global change? How can collaborative foresight and scenario-based methods help to improve decision-making?

In our study, researchers worked alongside stakeholders to design scenarios for the WIAM challenges of the future. This paper presents the results of our original foresight approach, which called on the combined scientific and operational expertise of a team of specialists to generate scenarios up until 2070. In the field of water, relatively little attention has been devoted to the use of foresight in decision-making (e.g. Hatzilacou *et al.* 2007; Rinaudo *et al.* 2012; Graveline *et al.* 2014; Proskuryakova *et al.* 2018). In other fields, such as urban planning (Masson *et al.* 2014), or coastal risk management (Rocle *et al.* 2020), integrative scenario-based approaches are commonly used to explore how governance can best be adapted in the face of global change. The present study aims to contribute to 'actionable knowledge' (Kirchhoff *et al.* 2013) to aid effective decision-making in WIAM.

This paper begins by using four case studies to show how the original foresight method we developed can help to answer questions relating to global change in the context of WIAM. Following this, we present the results of the study, specifically the four main scenarios showing different WIAM pathways between now and 2070. Next, we discuss how each of the scenarios can contribute to the objectives of simulation, strategy, and learning in the context of WIAM. Finally, we examine the benefits and limitations of a scenario-based approach in improving water management.

METHODS

Issues, questions and analytical framework

The technical performance of a water supply service is typically monitored using three straightforward indicators: continuity of service (in terms of volume flow and pressure), sanitary quality of drinking water, and impacts on the natural and human environment. However, when combined with uncertainty and complexity, WIAM can become a 'wicked' policy problem. The ability to innovate is linked to anticipatory governance (Quay 2010), or the practice of responding to global change by designing possible pathways and flexible strategies (Jordan & Huitema 2014; Rocle *et al.* 2020).

A more holistic approach is therefore required to enhance the traditional planning paradigm. With this in mind, our study aims to examine in parallel the technical dimensions of performance, developments in the demands made by society, governance issues, and the effects of climate change, thus promoting a new integrative approach to the study of WIAM. Its results and conclusions are designed to help policy makers, consultants and utilities to pave the way for proactive long-term decision-making processes, based on anticipation and foresight. In doing so, this research seeks to contribute to a broader body of reflection aimed at escaping the limitations of partitioned approaches and day-to-day management and decision-making.

Concepts and methods from a number of other studies reference the 'politics of anticipation' (Granjou *et al.* 2017). Here, we present anticipatory governance as a new model of decision-making under high levels of uncertainty, based on the concepts of *foresight* and flexibility (Quay 2010). '*Foresight is an elaboration based on thoughtful methods of conjecture on the evolution and future states of systems whose future is perceived as an issue within their structured discussion*' (Mermet 2005, p. 75 – translated by the authors). For us, foresight is a way to broaden thinking in relation to the future. It is important to take into account uncertainties and discontinuities (van Asselt *et al.* 2010) when exploring the notion of 'futuribles': a neologism of 'future' and 'possible' created by de Jouvenel (1964). The method used should include a multitude of viewpoints and give newfound choices (Bradfield *et al.* 2005).

Many foresight approaches are available, each with their own set of pros and cons (Van Notten *et al.* 2003). The most suitable approach should be selected based on the means and goals of the foresight exercise (van Asselt *et al.* 2010). We opted for the 'scenario method' (Bradfield *et al.* 2005), which simulates each part of a chain of events leading a system to a future situation, in a plausible and consistent way, and provides an overall view of this chain of events (Julien *et al.* 1975). Its advantages include its ability to deal with complex systems whose possible evolutions are only partially determined (Durance & Godet 2010), as in the case of drinking water services in the context of global change (Gober 2013).

We built an original, reflexive and integrative foresight methodology, 'weaving together' knowledge from a variety of disciplines. Our approach was also participatory and inclusive, as it involved researchers, practitioners, experts, politicians, policymakers, lay people, etc., to call on the broadest possible range of knowledge for WIAM. It was based on empirical (Godet & Durance 2011) and theoretical knowledge (Julien *et al.* 1975; Van Notten *et al.* 2003; Mermet 2005). This foresight provided the opportunity to reflect on WIAM strategies that (i) cover the issues of global change (climate change, shifts in the quantity and quality of resources available, technological changes, changes in consumption patterns, legislation, mobilities, lifestyles and ways of living, governance, etc.), (ii) heal the rift between the 'large' water cycle (river basin) and the 'small' water cycle (drinking water and sanitation) and make it possible to treat drinking water supply as an integrated whole (i.e. to consider interdependencies between territories, resources, infrastructures, service provided to users, management, normative systems, practices, etc.), and (iii) explicitly take into consideration the long-term issues (which means moving from programming to anticipation).

Selecting our case studies

Our case studies relating to the study of impacts of global change on WIAM were chosen based on five main criteria: (i) contrasted spatial configurations (urban, peri-urban, rural, coastal, economic activities) and dynamics (seasonal influence of tourism, metropolitan dynamics, etc.), (ii) contrasting types of water management and modes of organisation (public vs private water management, type of management organisation, water plan area (SAGE – schéma d'aménagement et de gestion des eaux)), (iii) focused local issues (demographics, seasonal attractiveness, non-domestic water uses, cost of drinking water production, inter-sectorial conflicts for water resources, etc.), (iv) availability of data and quality of the information system for WIAM, and (v) contrasting finance and investment capacities.

Four public water management organisations from two local authorities in the Nouvelle-Aquitaine region of France (departments of Gironde and of Charente-Maritime) were selected as case studies: the city of Cestas in southwest Bordeaux, the inter-municipal water supply association of Carbon-Blanc in northeast Bordeaux (SIAO), the inter-municipal water supply association of Bassanne-Dropt-Garonne located in southeast Bordeaux (SIAEPA) and Oléron Island (see Figure 1).

Organisation of the foresight group

A range of interdisciplinary and inter-professional seminars were held to construct possible future scenarios, bearing in mind that the final purpose of our study was to translate those scenarios into possible developments and requirements in infrastructure, and ultimately into workable WIAM strategies. In the particular case of the scenario method, which involves building equally plausible scenarios, this should not be seen solely as a 'technique', nor should it be based only on 'brainstorming'. Instead, scenarios should follow a number of guiding principles and rules (Durance & Godet 2010; van Asselt *et al.* 2010), for research in particular.

In any study of this type, a reasonable balance of 'internal' and 'external participants (i.e. respectively, researchers and stakeholders) is essential. To ensure this, our foresight group was made up of 22 people in total (twelve researchers in water engineering, statistics, economics and sociology, and ten stakeholders – policy makers, water supply and groundwater managers, municipal representatives, a philosopher who acted as the 'uninformed', etc.).

An initial one-day working session for researchers only was held in June 2018. A further four one-day workshops were organised for the entire foresight group over a 4-month period between October 2018 and January 2019.

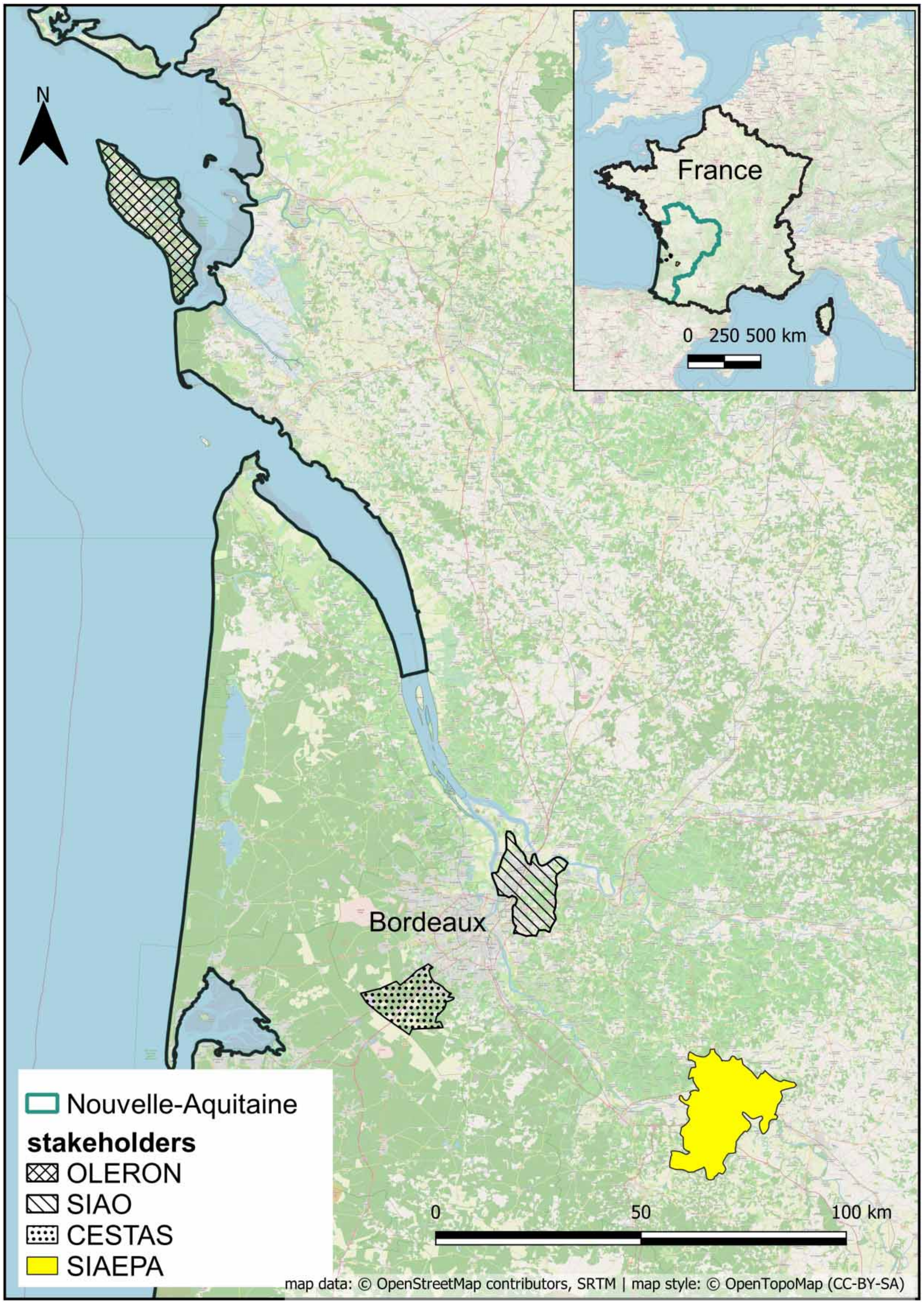


Figure 1 | Location of our case studies.

Between workshops, researchers worked individually to produce content to motivate debate.

The first step, at the researchers-only workshop, was to clearly identify the problem we were trying to address, and then break that problem down into smaller parts, which we referred to as 'components'. Following in-depth analysis and discussion, the initial definition of the problem was as follows: 'supplying water destined for human consumption'. The scope of this question is broad enough to cover a multitude of issues, be they industrial or agricultural in nature. As a spatial area for our study, we chose the Nouvelle-Aquitaine region, chiefly for the rich variety of situations it offers, but also because issues of governance are much harder to tackle on a smaller scale. As a timeframe, we opted for a minimum of 50 years, to allow for the general inertia of water supply infrastructure and networks. It was subsequently decided that the full title of our foresight study, or 'system', would be: 'Supplying water destined for human consumption in Nouvelle-Aquitaine up until 2070'.

Variables and components

During the researchers-only working session, time was spent reflecting on the 'components' of the 'system'. Scenarios up until 2070 were designed based on five components: (i) organisation and operation of the water supply service, (ii) social demands in terms of drinking water, (iii) governance, (iv) territorial dynamics, and (v) the structural context. Each component was then described using variables that matter for the future of drinking water supply in Nouvelle-Aquitaine in 2070 (Figure 2). At the end, each foresight scenario was made up of a total of 21 variables.

To ensure that scenarios are not purely a product of people's imagination, but rather part of a more thorough approach, foresight calls for a clear description of each variable. 'Variable' sheets were thus completed with the objective of establishing reliable and reflexive projections of the state of each variable within the system, based on assumptions made concerning the past and current states of the variable. This work, carried out collectively, sought

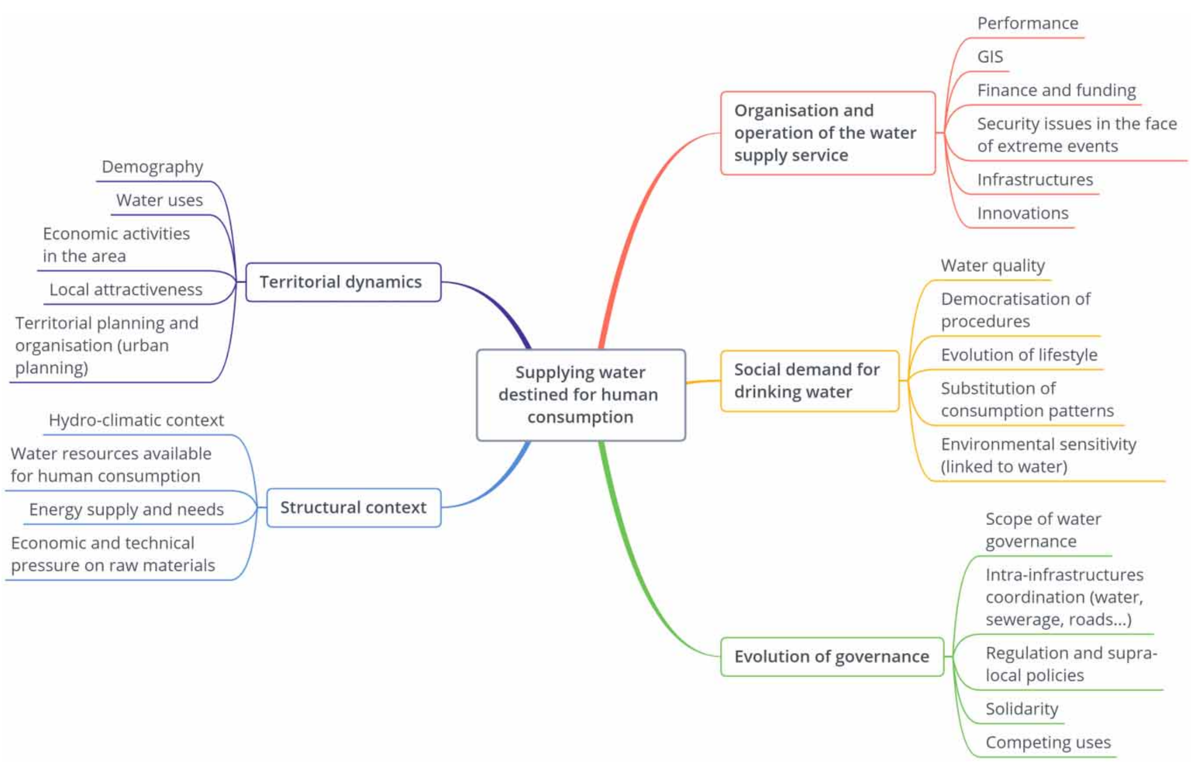


Figure 2 | Our system: five components and twenty-one variables.

to give credibility to the scenarios for decision-making purposes (Durance & Godet 2010). Exploring the future is not purely a matter of chance, since foresight is about the capacity to identify, beyond that which is clearly visible, the factors shaping changes (Godet & Durance 2011). The 15-page description of each variable therefore not only contains a retrospective analysis and assessment of the current situation, but also some 'dominant trends' (i.e. slow but steady changes), 'seeds of change' (i.e. trends currently fairly constant but likely to play a more significant role in the future) as well as uncertainties and 'wild cards' (defined by Petersen (1999) as '*low-probability, high impact event[s] that [are] so large and/or arrive so fast that social systems are not able to effectively respond to [them]*').

Component-scale micro-scenarios were therefore designed, with the goal of building a narrative combining different assumptions relating to the future of the variables involved (Mietzner & Reger 2005). It is important to be able to map out a road between these assumptions that brings consistency, relevance and reasonableness to the narrative (Durance & Godet 2010; van Asselt *et al.* 2010). The articulation between synchronic analysis – that is to say, a snapshot taken at one moment in time – and diachronic analysis, i.e. the process of getting to one point, is particularly important (Steinmüller 2018). For this task, a number of principles were laid down, the most important of which were (i) avoiding the 'worst', 'ideal', etc. scenario, (ii) agreeing on a business-as-usual baseline scenario, (iii) building trajectories and pathways, and (iv) highlighting the general ideas behind each macro-scenario (van Asselt *et al.* 2010). Based on the same principle, system-scale macro-scenarios were designed to represent a series of events occurring over time.

RESULTS

By combining the different pathways that could be taken by each variable, we designed micro-scenarios and, by combining these, we generated four macro-scenarios describing the possible situations for drinking water resources and infrastructures between now and 2070. Following this, these same scenarios were used for the simulation of future infrastructure needs.

Foresight scenarios

Once the skeleton of each scenario (i.e. the story-telling) had been created, the scenario itself was put into narrative form by adding the right 'binders', highlighting the driving and key variables and ensuring the scenario was coherent and consistent (Durance & Godet 2010; van Asselt *et al.* 2010). These scenarios (S1–S4) are as contrasted as possible, based on scientific knowledge and participative animation.

S1: eco-solidarity-driven centralised management

In 2070, following continued public pressure over the last few decades, ecological issues have reached the top of the public and political agenda. Voluntarist environmental and climate policies have gradually gained traction at both international and local level. Water is now recognised as a precious natural resource, and users are happy to reduce their consumption. National ecological transition and green growth policies have filtered down into the Nouvelle-Aquitaine region, where the volume of water available continues to be heavily impacted by climate change. Central government regulations, particularly those relating to the quality of raw water, have become much more stringent. 'Green' farming practices have become the rule rather than the exception. A national body has been created which lays down rules relating to water sharing and management.

Heavy social demand placed on traditional water services has led the government to promote utilities managed by a national centralised agency, the cost of which is met through a specific tax on consumption (water users pay for water). A fixed tariff is applied to the entire country.

Bringing water management back into public ownership has made it much easier to coordinate with the services responsible for other areas of infrastructure. To ensure that water is shared out in the most equitable way possible, distribution networks are more and more interconnected. An ever-growing number of sensors are installed and shared databases are centrally used to monitor infrastructure and decide on how assets are to be managed.

S2: technocratic management led by regional planning

In 2070, social and ecological tension is high, coupled with enhanced levels of demographic growth in the Nouvelle

Aquitaine region. Climate change has become a priority issue. Restoring water quantity and quality has been one of the central objectives of the voluntarist ecological transition strategy adopted over the past few years. A principle of 'water conditionality' is used to target priority water users and impose changes, specifically for domestic users and agricultural users irrigating high-value crops. Water utilities have equipped themselves with information systems, and make use of a range of sanitary and environmental performance indicators. A sophisticated network of sensors allows for instantaneous monitoring of water use across the entire network. With this high level of automation, it is possible to control costs, reduce water losses, and manage infrastructure in a coordinated way across multiple utilities. In some cases, dual collective networks are established.

The relatively high cost of these actions is met through the creation of a specific tax (water users pay for water), and through stringent application of the 'polluter pays' principle for all uses. Adherence to sanitary and environmental requirements pushes up the price of water, which is set at regional level and based on each users' financial situation.

A reduction in individual consumption, combined with changes to the agricultural production model, has allowed a significant amount of pressure on water resources to be alleviated. Conflicts between different water uses, particularly in terms of agriculture, are now confined to occasional localised incidents.

S3: pragmatic management based on trial and error

By 2070, the Nouvelle Aquitaine region has been affected by intense global warming for several decades. Marred by uncertainty surrounding raw materials and water availability, regional water services practice reactive management, with the aim of ensuring continuity of service through existing infrastructure. The priority is to ensure the quality of water at source, rather than investing in sophisticated and costly treatment programs. There is a general dependence on winter storage of water, which is often irregular in its availability, leading to intermittent excessive use of underground water sources.

Innovations in technology and organisation are used to enhance service performance. There is a move towards the use of sensors, both along the network and at user exit points of use. Consumption is monitored in real time and data are shared between services. The cost of introducing all of this new technology has pushed up the price of water.

The region has continued its swing towards more tertiary type activities, while continuing to cultivate high-value irrigated crops. The Gironde department, where the city of Bordeaux is located, and coastal regions have continued to attract new residents, leading to lower populations in inland areas. This territorial inequality has led to a rivalry between urban and rural areas in terms of uneven demand for water (unequal territorial distribution of water resources) and non-uniform management of water networks and their level of performance.

EU regulations relating to raw water quality have become much more stringent, imposing minimum results and sanctions. Water users are called upon to restrict their water consumption through continuous monitoring, using both technical solutions and financial incentives.

S4: strategic and individualist management

In 2070, global warming will have reached very high levels. Several developed countries have favoured investing in technological innovations rather than changing their production and consumption models.

In the Nouvelle Aquitaine region, water resources, sensitive to climate change, are less abundant and of poorer quality. This leads to an upsurge in conflicts of use.

Water utilities have developed safeguarding strategies based on technical innovation. Climate change tends to increase water consumption. Water management, now decentralised to various extents and fragmented, varies from one territory and set of users to another. Management efforts tend to be focused on collective and/or individual supply of raw water, with purification for drinking purposes delegated to (very) local organisations. The general consensus that public access to drinkable tap water is a universal right has slowly begun to fade.

Service performance is assessed based on economic criteria. Water price and service quality vary significantly from place to place, and depending on the level of investment. An absolute basic level of service is provided, which can be topped up with additional paid-for options. The growing number of people being disconnected results in networks falling into disrepair. A strategic renewal program is put together using an information system.

Net migration to the Nouvelle Aquitaine region remains positive, but there is still an ageing population, with reduced quality of life throughout the region. The local authority continues to support intensive, high-performance farming based on significant levels of irrigation.

Simulating future infrastructure needs

Once we had obtained the outcomes from our scenarios, we ran further simulations to visualise what a given infrastructure network would look like under each set of assumptions, and under different territorial configurations. The reason for this was that while our initial scenarios covered a number of 'structural context' and 'governance' issues at regional level, reasoning at this scale is not sufficient when examining potential infrastructure requirements, which ideally should be addressed at the smaller 'utility' level. To achieve this, we applied all of our scenarios to our four case studies.

Modelling was carried out using the Porteau software package, a specially-designed tool to study the hydraulic operation of pressurised looped water distribution systems (http://porteau.irstea.fr/). The software's first action is to model the current state of the drinking water distribution system. Our aim was to modify this modelling method to simulate how the system would operate for each foresight scenario, thus identifying: (i) areas in which local infrastructure would not be able to handle the demand placed on it by a given scenario, (ii) areas in which new infrastructure would have to be installed, and (iii) the most appropriate pipe diameters.

Different size parameters were used by the foresight group when creating their scenarios. Key considerations were the number of customers and the effective level of water consumption. One of the first things we did with this modelling approach was to distribute new subscribers spatially, using existing spatial maps and the urban development strategy from each foresight scenario. For example, in S3, the number of customers will be unevenly distributed between rural and urban areas. In S4, sharp rises in sea levels would likely place significant strain on construction sites close to the coast. With our method, the necessary network extensions to deal with these issues can be modelled. To ensure demand does not outstrip supply, consumption trends should be defined for each foresight scenario, as a daily profile and/or an annual volume. For example, in S1, there is a large (40%) decrease in annual consumption, whereas S2 shows only a 25% drop. S3 shows a stabilisation in the current decline in demand for water, while in S4, demand increases by around 20%.

To simulate how the system would likely behave during peak demand periods (instantaneous peak flow on a peak day), a daily peak coefficient was used. Table 1 presents all the values, sorted by scenario and case study, combined with the efficiency of each network studied. To design the pipes for a distribution subsystem, the 'Opointe' model of the Porteau software (Piller & Brémond 2002) uses a probability-based methodology whereby the parameters are those usually applied, calculated based on hypothetical demand.

Under each scenario, various other items affecting network construction can be added. These could be, for example, interconnections (in S1 and S4), dual network systems (in S2) or a dam construction project (in S3 for SIAEPA). Once these various modifications have been completed, the simulation can start. The objective of this tool is to solve problems such as low water pressure, an overuse of one resource, and to determine the adjustments needed by resizing the network in order to fulfil different performance criteria.

Figure 3 shows the distribution of new consumers in Cestas for S4, illustrating the suburban colonisation of natural space.

Figure 4 shows the effect of S4 on Oléron Island. As the sea level rises (following the IPCC, we assume a sea level

Table 1 | Modelling parameters by scenario and network

		Oléron	Cestas	SIAO	SIAEPA
S1	Peak Coefficient	1.4	1.4	1.4	1.4
	Efficiency	90%	90%	90%	90%
S2	Peak Coefficient	1.7	1.7	1.7	1.7
	Efficiency	85%	85%	85%	75%
S3	Peak Coefficient	1.2	1.2	1.2	1.4
	Efficiency	90%	90%	90%	70%
S4	Peak Coefficient	2	2	2	1.4
	Efficiency	75%	70%	70%	75%

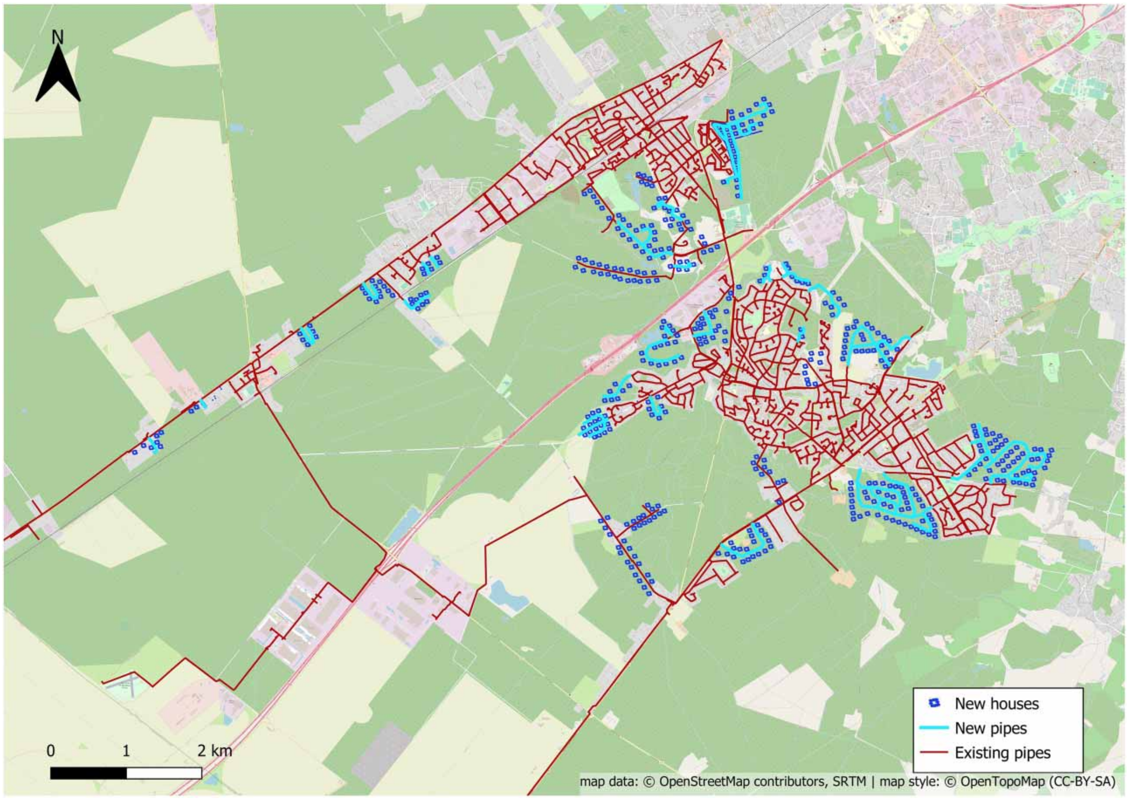


Figure 3 | S4 applied to Cestas.

increase of +2m by 2070) some villages (or parts of them) are deserted. And, more importantly for the system resilience, loop pipes crossing flooded area are abandoned, forcing the designer to increase other paths, or duplicate some main pipes to ensure continuity of distribution in case of a burst.

DISCUSSION

To support policy makers and WIAM organisations in assessing their preparedness faced with issues of global change, we aim to share and discuss various categories of linked results: (i) WIAM strategies and (ii) education and awareness-raising efforts.

Water infrastructure asset management strategies

WIAM involves planning gradual changes to a network in order to (i) maintain, or even improve, the quality of service provided to users, while keeping outages to a minimum, reducing losses, and ensuring suitable water quality and pressure, and (ii) adapt its configuration (diameter and location of pipes) to suit levels of water available, demand for water, and wider territorial development goals. Any change of this sort being made to a water network will generally be slow: typically, the total annual length of pipes renewed is less than 2% of the total. In recent years, this renewal rate has been as low as 0.6% in mainland France. And the cost of replacing pipes needs to be compatible with the multi-annual investment plan, which in turn defines the price paid by the end user.

In practical terms, annual removal from service and/or replacement of pipes can be as a result of excessively high breakage or leakage rates, or may also take place when the material they are made from no longer conforms to safety regulations (e.g. PVC pipes made before 1980 which are a source of vinyl chloride monomer, or pipes made of asbestos cement which are expensive and complicated to maintain). In some cases, pipe replacement has nothing to do with their actual physical state, but is carried out as

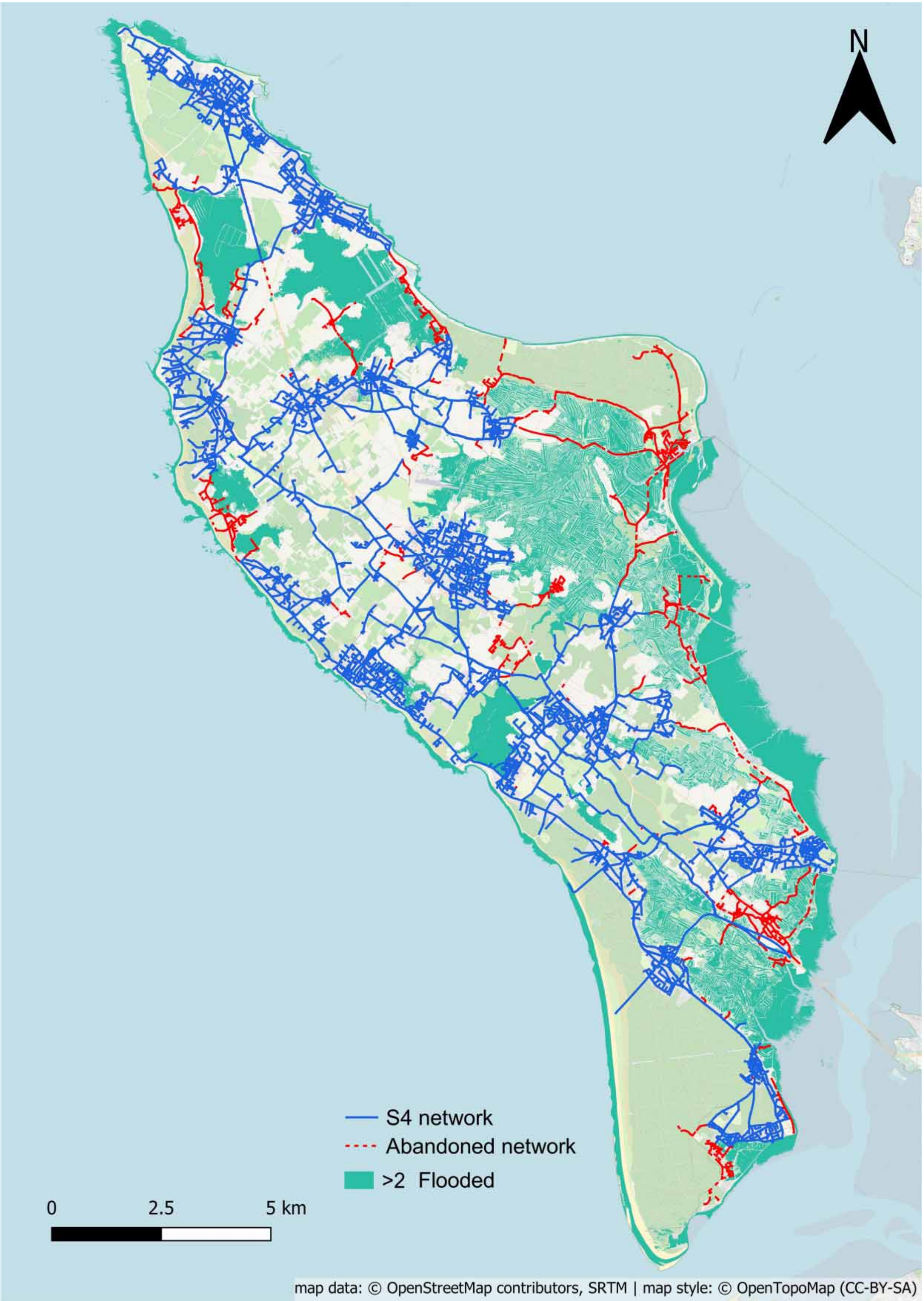


Figure 4 | S4 applied to the Oléron Island.

part of a broader plan to reconfigure a given network. Finally, 'opportunistic' replacement may happen in parallel with work being carried out on other infrastructure (most often roadworks, but also gas, electricity, etc.). WIAM governance, which generally aims to work with rather than to be ruled by territorial development, has to be based on a strategic vision of the network and the capacity to anticipate its performance. This is where a computerised simulation system is particularly useful, as it provides the possibility to compare WIAM strategies in a number of possible (foresight) scenarios. Such a long-term simulation tool, written in R code, is intended to be integrated into the information systems of the four water utilities (it is currently under development as a deliverable of the final step of the ChaPEeau project; eventually, this work is aimed at being pursued in future projects and becoming more general).

This kind of tool calls for the combined used of a number of different models (Le Gat 2018). Probabilistic models tend to focus on the degradation of pipes and the probability that they will be affected by roadworks, changes in demand, changes in resource availability, and land planning (Le Gat 2015). Other types of models, more deterministic in nature, tend to relate to the costs involved in repair, removal from service, and replacement/installation. As shown in Figure 5, the long-term simulation algorithm involves exploring possible pathways for every pipe, combined with probabilities. The algorithm runs simulations at yearly time steps between 2018 and 2070. This approach avoids the phenomenon of combinatory explosion by grouping together concurrent pathways involving replacement of a pipe in the same year.

Each simulation is based on an initial network state (listing all network segments of pipes by their year of installation, material type, diameter, and length) and a final state (including the initial segments as well as those created between 2018 and 2070). Two sets of hypotheses are employed:

- Hypotheses group 1 (management): total replacement budget, removal from service and installation of new pipes year on year, budget shares devoted to planned and opportunistic replacement, and utility's awareness of planned roadworks.
- Hypotheses group 2 (context): level of roadworks and land development.

The most difficult part of designing simulations such as these is the relevance of the way in which the foresight scenarios condition the final state and management hypotheses. There is still a certain margin for interpretation, meaning

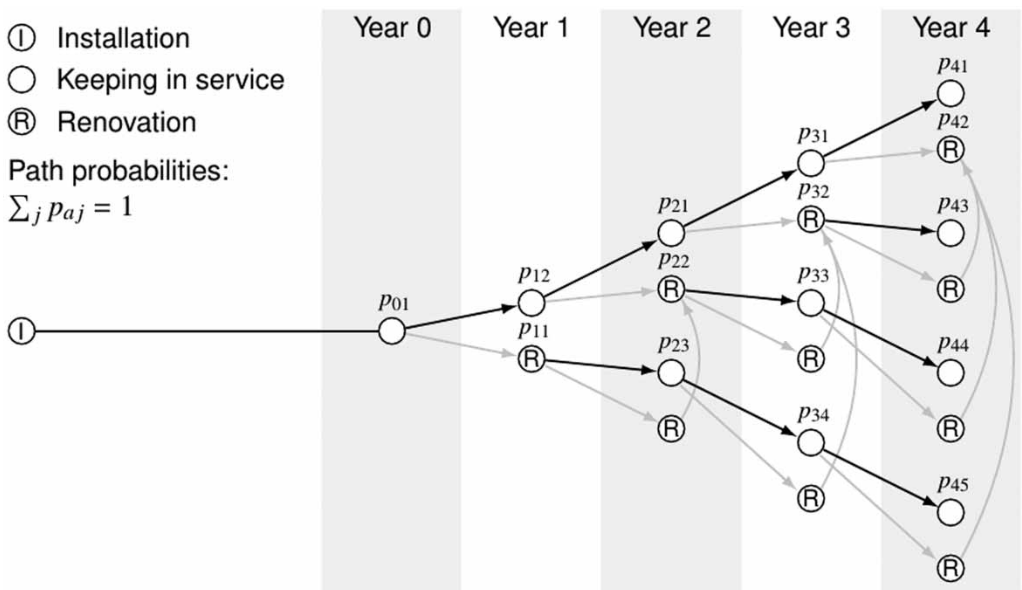


Figure 5 | Simulation tree of possible paths for a segment.

that one given scenario can be transformed into a variety of long-term simulations.

One of the other objectives of long-term simulations is to provide budget strategies based on rehabilitation, replacement and extension works. These strategies can then be used to define a strategic investment plan over a specific period: e.g. 5 years. This process (strategies followed by investment plans) can be repeated at the end of each period, enhanced each time with up-to-date knowledge.

Education and awareness-raising

One significant advantage of our foresight approach is the educational value it has for water managers (Rhisiart *et al.* 2015). The use of scenarios tends to open people's minds to broader views and expectable, challenging and visionary alternatives (Bezold 2010).

We held a seminar for water managers and policy makers to present our various foresight scenarios, and the methods used to create them (Figure 6). The aim of these workshops was to make the participants think critically about the way they work, and reflect on new outlooks. General feedback was that they were highly instructive for all involved, encouraging the participants to reflect on the importance of structured long-term thinking (e.g. identifying heavy trends, etc.). Practitioners who took part in the foresight group stated that they found the experience somewhat 'destabilising', and that it really caused them to change the way they saw things. When faced with uncertainty, the capacity to anticipate unexpected and challenging situations, including shifts following extreme events (e.g. Covid 19) becomes a resource for action (Shepherd *et al.* 2018).

Along with more traditional tools used by water experts for WIAM, visualisation has become very much the tool of choice in the digital era to raise public awareness of climate change (Sheppard *et al.* 2008). User-clients-citizens' involvement has become an increasingly important feature of new WIAM models (Amblard *et al.* 2016), with social media, videos, design, etc. helping to provide persuasive imagery relating to issues of drinking water, making them aware of the potential effects of global change on their everyday lives in the years and decades ahead. We have made available a number of short films showing the main features of each scenario on the internet (all videos are available in English and French at: https://www6.bordeaux-aquitaine.inrae.fr/etbx/Toutes-les-actualites/Projet-Chapeau) and on social media, which provide a compelling insight into these changes (Sheppard *et al.* 2008).

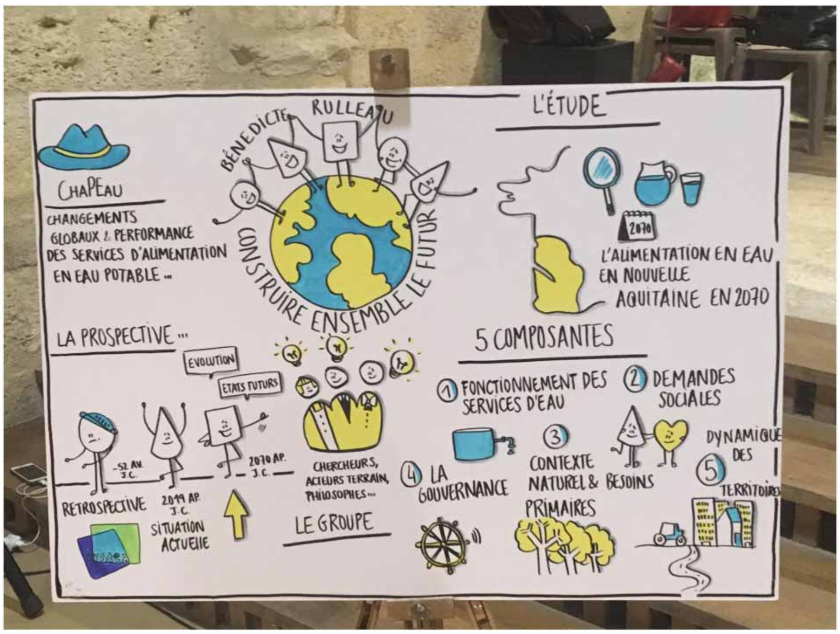


Figure 6 | Live drawing by Louise Plantin made during the stakeholder seminar; © 2019 Louise Plantin.

CONCLUSION

This paper describes the approach and methodology used in a research project focusing on long-term adaptation of WIAM strategies to create scenarios up until 2070. Four contrasting scenarios, representing possible futures for drinking water supply in the Nouvelle-Aquitaine region in southwest France, were developed by a foresight group consisting of researchers from different disciplines and areas of expertise and stakeholders from different organisations. These scenarios are based on five components: organisation and operation of the water supply service, social demand for drinking water, water governance, territorial dynamics, and the overall context. These scenarios were then dealt with respect to four case studies in the area, chosen for their contrasting characteristics. The ultimate aim of this work is to measure the consequences of the scenarios for WIAM strategies in the four case studies.

The main contribution of our scenario-based approach is that it provides, through a multidisciplinary group of stakeholders and scientists, a clear method by which to address the complex nature of WIAM from a variety of standpoints (technical, financial, social, governance, etc.). Bringing together participants from a variety of backgrounds makes it possible to 'think outside of the box', broadening reflection beyond that of scientists or engineers alone. By using case studies to model long-term pathways, more objective and imaginative planning and decision-making possibilities can be achieved. The other clear advantage of our approach is increased public awareness of the consequences of global change on water supply, achieved through our video resources.

However, foresight is not a science, and we have no means of verifying whether or not our working assumptions will occur before the end of the foresight exercise (2070). What is important is that the methodology be defensible and that it be presented in a fully transparent manner so that it may be subjected to suitable scrutiny. Although some people see foresight as a way to predict the future, in fact the aim is to help forecast the future or to clarify alternatives. More simply, foresight makes the future potentially visible and provides an opportunity to discuss it, in order to be able to inform decision-making. Of course, the future cannot be written and uncertainties surround us, but more than ever, designing WIAM strategies to deal with the challenges of global change calls for imagination.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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