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DOI:
10.3390/su14084586

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Document Version
Publisher's PDF, also known as Version of record

Citation for published version (Harvard):
Bowman, BM, Hunt, DVL & Rogers, CDF 2022, 'Gazing into the Crystal Ball: A Review of Futures Analysis to Promote Environmental Justice in the UK Water Industry', *Sustainability*, vol. 14, no. 8, 4586. https://doi.org/10.3390/su14084586

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Review

Gazing into the Crystal Ball: A Review of Futures Analysis to Promote Environmental Justice in the UK Water Industry

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Abstract: Water is a vital and multifunctional resource for our society, economy and ecosystems; thus, how water is managed now and into the future has wide-reaching consequences. Sustainable water management and environmental justice therefore become key topics; a discussion of these terms is explored in the context of the UK water industry, which provides the focus for this study. This systematic review explores how considerations of the future have been applied in water research. The literature is reviewed with respect to (1) defining the end goal, (2) the use of futures analysis and (3) possible evaluation methods, including a discussion on the boundaries applied to each of the studies. A growing body of research associated with decision-making applying future scenarios was identified. However, the methods of application varied substantially, with holistic analyses largely lacking. The formulation of methods appears to be specific to the goal that is sought as well as the cultural influence of the region in which the analysis was developed and deployed. This paper presents a case for the visualisation of catchment characteristics and interdependencies to enable transparency in decision-making. This should reflect not only the current system but also a range of potential futures to enable appraisal of impacts.

Keywords: decision support; environmental justice; futures analysis; scenarios; sustainability; water; wastewater

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Citation: Bowman, B.M.; Hunt, D.V.L.; Rogers, C.D.F. Gazing into the Crystal Ball: A Review of Futures Analysis to Promote Environmental Justice in the UK Water Industry. *Sustainability* **2022**, *14*, 4586. https://doi.org/10.3390/su14084586

Academic Editor: Bo Jiang

Received: 7 March 2022
Accepted: 8 April 2022
Published: 12 April 2022

1. Introduction

The UK water industry is subject to a rolling cycle of investment to meet regulatory requirements. Moreover, this sits within the context of a constant state of flux due to the changing climate and political and societal priorities. Therefore, interventions such as improved wastewater treatment (to reduce nutrient levels entering rivers) are likely to experience conditions over the asset life, which vary widely from design parameters. This leads to a cycle of modification and upgrading in order to maintain or improve treatment processes which could include abortive investment. In addition to the direct conditions relating to water industry assets, there are also surrounding influences (indirect conditions) that constitute a range of challenges and opportunities and which could unfold in a variety of ways. These factors combine to create an environment of uncertainty within which the water industry must operate. This systematic literature review explores how future uncertainty can be considered through associated decision-support systems, ultimately leading to appropriate interventions being adopted.

Within urban development, systemic interventions are likely to be subject to a range of interdependencies. One way to explore these and to better understand their impacts is through the exploration of extreme yet plausible archetypal future scenarios [1,2]. Allied to this is the use of foresight to develop a number of visions for how cities of the future may have adapted, or not, to water cycle management [3].

The question remains over whether future scenarios and the use of foresight could be applied within the context and focus of the UK water industry (the provider) as opposed to the urban context (the receiver) per se. Specifically, there is a question of whether such an approach could enable a more complete understanding of uncertainty and risks associated with interventions and how this impacts the delivery of wide-reaching sustainability goals whilst maintaining the public health duty of a water company. Prior to exploring the literature, there follows a discussion of sustainability, and subsequently environmental justice, both broadly and within the context of the UK water industry.

2. Sustainability Goals within the UK Water Industry

Sustainability is a concept that is discussed from a range of perspectives. Most frequently, in the realms of sustainable development, the 1987 definition by the United Nations Brundtland Commission is used: 'Meeting the needs of the present without compromising the ability of future generations to meet their own needs' [4]. The application of this definition is then further conceptualised as consisting of three pillars—social, economic and environmental [5]—as depicted in the visualisation in Figure 1.

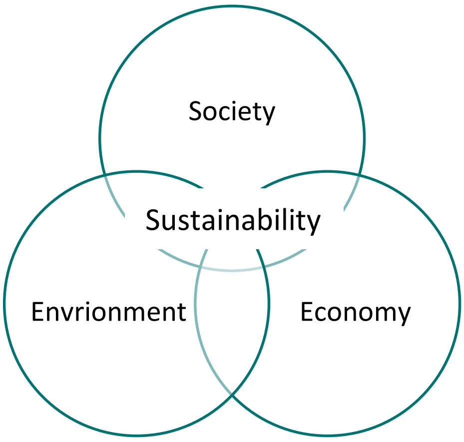


Figure 1. Visualisation of sustainability. Reprinted from Purvis et al. [5].

In the global context, discussion of sustainability has led to the 2015 adoption of the United Nations Sustainable Development Goals [6]. Since this agreement, global pressures have escalated around two themes: climate and environmental change; and increasing inequality, both within and between nations [7], leading to discussions of justice.

Within infrastructure discussions, goals of robustness and resilience are often considered to be precursors to achieving sustainability and, subsequently, justice [8–11]. Indeed, Sadr [8] presents this as a hierarchy of aspiration for which each stage acts as a building block for the next. In this hierarchy, environmental justice can be seen as a specific form of justice in which environmental and social equity are prioritised. Contrastingly, water justice has a tendency to relate to the human experience [12,13], in particular to the fair and equitable access to water through the discussion and practice of distributive justice.

Within the context of the global provision of water and sanitation, this leads to the question of whether sustainability, environmental justice and water justice are desired goals. Arguably, they could all be, although the outcomes and endpoints vary. In this paper, due to the mature status of the UK water industry in the provision of public health needs, environmental justice is proffered as the goal. This is to ensure that the voice of nature is represented alongside the needs of humans, both now and into the future.

Various ownership and regulatory models for water service provision are in place globally, and several studies explore how this may influence the degree to which social equity and environmental goals are incorporated [14–20]. This paper does not seek to extend this discussion due to its focus on the UK water industry, and in particular England and Wales.

Somewhat anomalously in the global context, the water industry in England and Wales was privatised in 1989 to stimulate investment from private sources for the continued provision of water and to drive improvements in wastewater treatment [21,22]. The situation differs across the devolved nations of the UK, so this text will focus on the water industry in England and Wales to provide consistency across the regulatory regime.

The primary function of the water industry, and specifically licensed water companies, is to perform the statutory duty to provide potable water and sanitation services to the population. Several regulatory bodies focus on complementary aspects of the water industry's functions. In addition to these regulators, there are several policy and advisory organisations, as well as complaints and appeals bodies, which collectively influence water companies and water retailers (Figure 2). Ofwat, through the Price Review process, is regarded as the means by which Defra is able to influence the direction of the water industry [23,24].

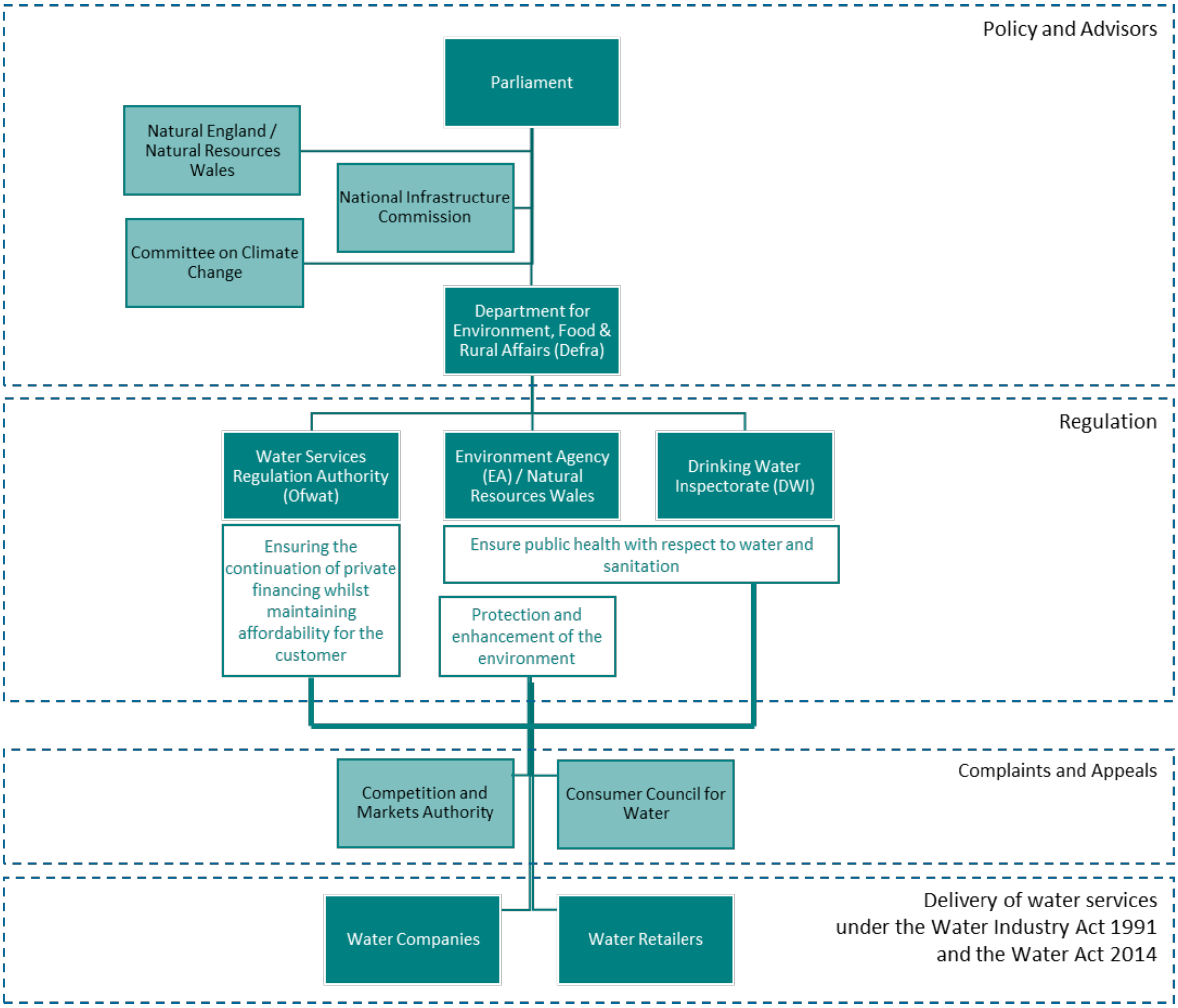


Figure 2. Regulatory structure of the Water Industry in England. In Wales Natural Resources Wales operates in the equivalent role to the Environment Agency.

The Water Act 2014 gave Ofwat, and thereby the UK water industry, an additional remit of long-term resilience of water and wastewater services [25]. Since then, a number of published government documents have incorporated resilience (Figure 3), which is typically thought of in infrastructure as the ability of a system to efficiently resist, adapt and recover from shocks [26]. Ofwat considers resilience in terms of financial, corporate and operational resilience to ensure that water and wastewater services are provided regardless of external disruption [25]. The 25-Year Environment Plan [27] gives prioritisation to the delivery of long-term resilience in infrastructure, supporting environmental standards with a focus on natural capital and including reference to intergenerational equity, which is echoed in later documents setting the strategic directive for Ofwat [23,24]. This implies that there is an ambition to move towards achieving justice themes. However, the language is deeply rooted in the provision of a robust and resilient water industry, indicating that although there may be some aspirational movement towards more mature themes, current application is at best tentative. Indeed, guidance for Price Review 2019 focused on providing resilience, with evidence subsequently that this passed into water company business plans for AMP7 [28]. The definition of resilience held within these publications, however, is developing to include language which would more typically be associated with environmental and water justice aspirations. This could see a shift in direction to more mature goals; however, unless the language also adapts, it could limit the capacity for change to be accepted and adopted both within and outside the water industry.

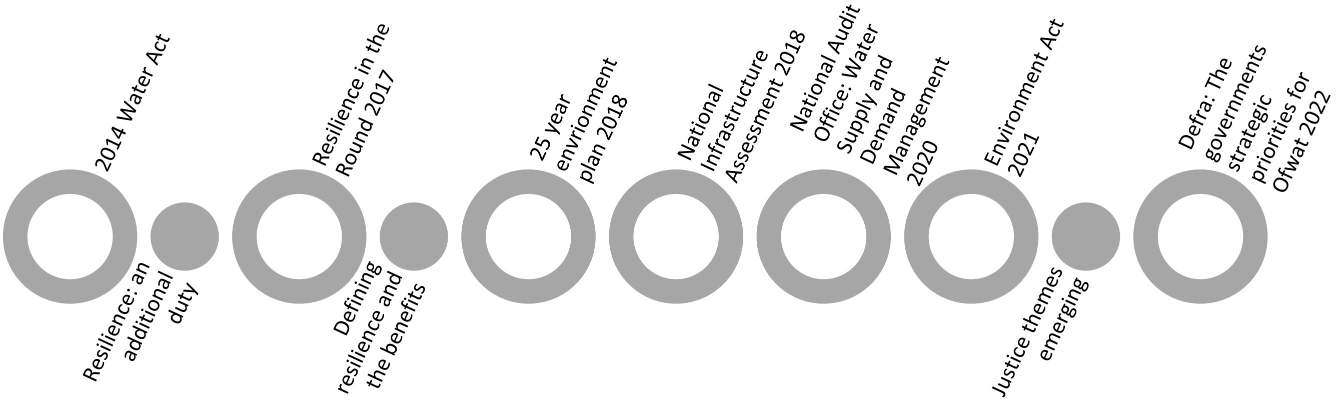


Figure 3. Governmental water industry publications highlighting the references to resilience and environmental justice.

The guidance in Price Review 2024 (PR24) is yet to be fully published, although consultation documents imply that adaptive planning may be featured [29,30]. Ofwat has recognised the uncertainty facing the water industry and the need for long-term strategies that incorporate adaptation and strive towards a no- or low-regrets approach. To support this, a series of factors are explored, predominantly in isolation, in 'high' and 'low' states, which are used to stress test water company strategies [30]. The water industry's adoption and development of this approach for PR24 is underway, with the application of scenarios, foresight and justice aspirations within these methods, as yet, unclear.

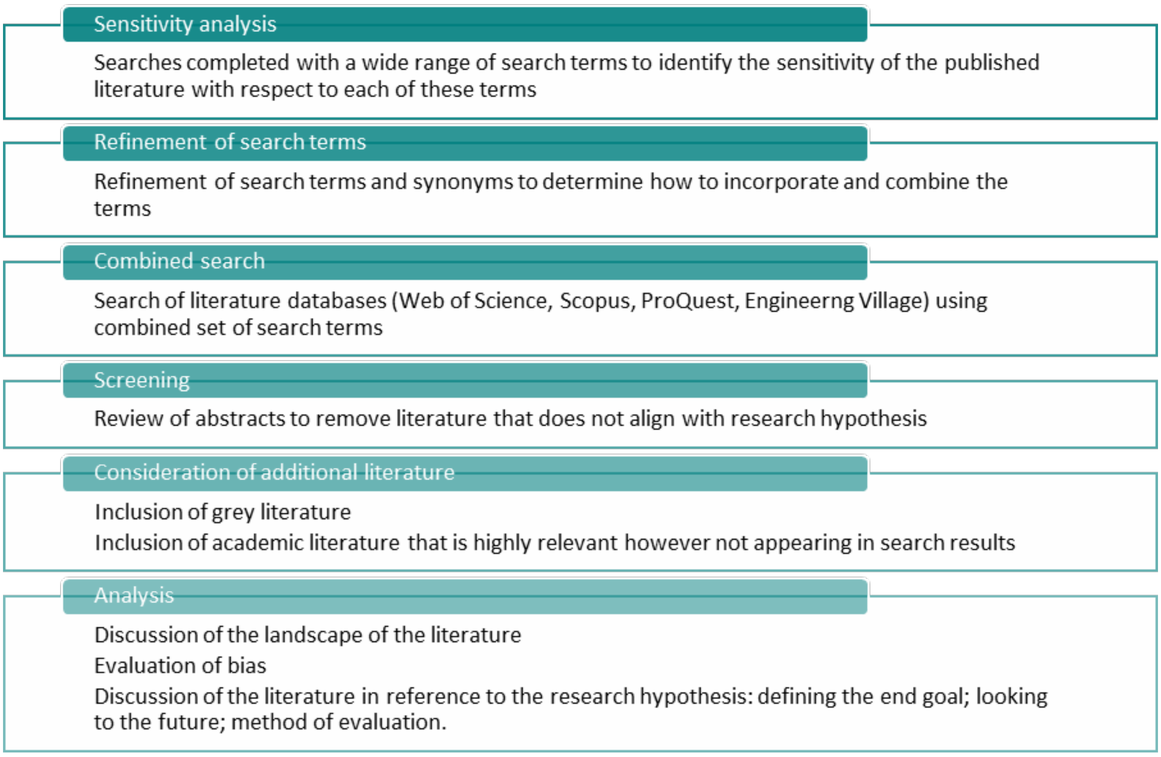
3. Method

A research hypothesis has been developed based on the regulatory context of the UK water industry and the key issue of sustainability:

The use of future scenarios would aid the UK water industry in addressing uncertainty in the delivery of sustainability goals whilst maintaining their public health duty.

The review will incorporate analysis of the literature in terms sustainability goals and environmental justice within the topics of (1) definition of the end goal, (2) use of futures analysis and (3) possible evaluation methods. These discussion areas are highlighted due to their importance in formulating a framework for decision support; defining the success of a decision; incorporating futures being necessary for consideration of sustainability and environmental justice; and a method of evaluation that includes the use of data in quantitative analysis.

To assess the current literature with the research hypothesis in mind a systematic review (Figure 4) has been undertaken to logically identify and analyse existing research against a specific question whilst aiming to minimise the opportunities for introducing bias. The method followed PRISMA guidelines as far as feasible [31]; the steps undertaken, search terms, and results are presented here.



Sensitivity analysis

Searches completed with a wide range of search terms to identify the sensitivity of the published literature with respect to each of these terms

Refinement of search terms

Refinement of search terms and synonyms to determine how to incorporate and combine the terms

Combined search

Search of literature databases (Web of Science, Scopus, ProQuest, Engineerng Village) using combined set of search terms

Screening

Review of abstracts to remove literature that does not align with research hypothesis

Consideration of additional literature

Inclusion of grey literature

Inclusion of academic literature that is highly relevant however not appearing in search results

Analysis

Discussion of the landscape of the literature

Evaluation of bias

Discussion of the literature in reference to the research hypothesis: defining the end goal; looking to the future; method of evaluation.

Figure 4. Literature review method.

Investigation of both the prevalence of search terms in the literature and the relevance to the topic under consideration enabled refinement of the terms used in the study (Table 1). Searches were not time-limited, and search results from the Web of Science, Scopus, ProQuest, and Engineering Village databases (Table 2) were combined to generate a list of 70 individual records.

Table 1. Literature review search terms.

Group	Description	Search Terms
1	Field of interest	Water/wastewater/sewage/sewer/river/catchment/watershed
2	Focus of impact No. 1	Biodivers */natural capital/ecosystems service */sustainab */environment *
3	Focus of impact No. 2	Soci */equity/justice/econom *
4	Analysis method	Future scenario/uncertain */risk/horizon scan
5	Interpretation or end use	Model */simulat */decision/strateg */index/system map/value map

* Allows for multiple word endings in a single search.

Table 2. Number of search results from the range of databases.

Group Searches	Web of Science	Scopus	ProQuest	Engineering Village
1&2	74,777	552,871	119,780	269,646
1&3	10,342	114,611	42,799	70,885
1&4	42,791	130,072	107 *	587 *
1&5	303,470	969,202	208,869	1,604,310
Combined (1, 2, 3, 4&5)	47	3 *	6 *	14 *

* Indicates that 'risk' and 'uncertain *' were removed from the combined search due to unmanageable number of returns when including these terms.

Whilst the focus is on the UK water industry, literature from outside the UK was included to gain a global perspective. Abstracts from these records were manually screened for relevance to the research hypothesis and ability to obtain full text records for each. This resulted in selection of 27 publications. Acknowledging that there is the potential for 'confirmation bias' to be introduced in the selection of results, a justification for selection decision was recorded in each case to reduce this risk.

There is an additional need to include highly relevant research that has not been extracted from the databases. The exclusion of these publications may be due to the use of broad keywords by the authors of the papers, meaning that the selected search terms did not identify this research in spite of its relevance.

This process resulted in a total of 31 publications for full analysis and discussion. A review of relevant grey literature was also incorporated into the literature review to place the academic literature alongside UK industry and regulatory contexts. Grey literature was identified from UK water industry regulator and water company publications.

4. Results

From the process described in Section 3, it was found that the majority of studies (55%) were carried out in Europe, with seven of these (23% of the selected studies), coming from the UK since 2013 (Figure 5).

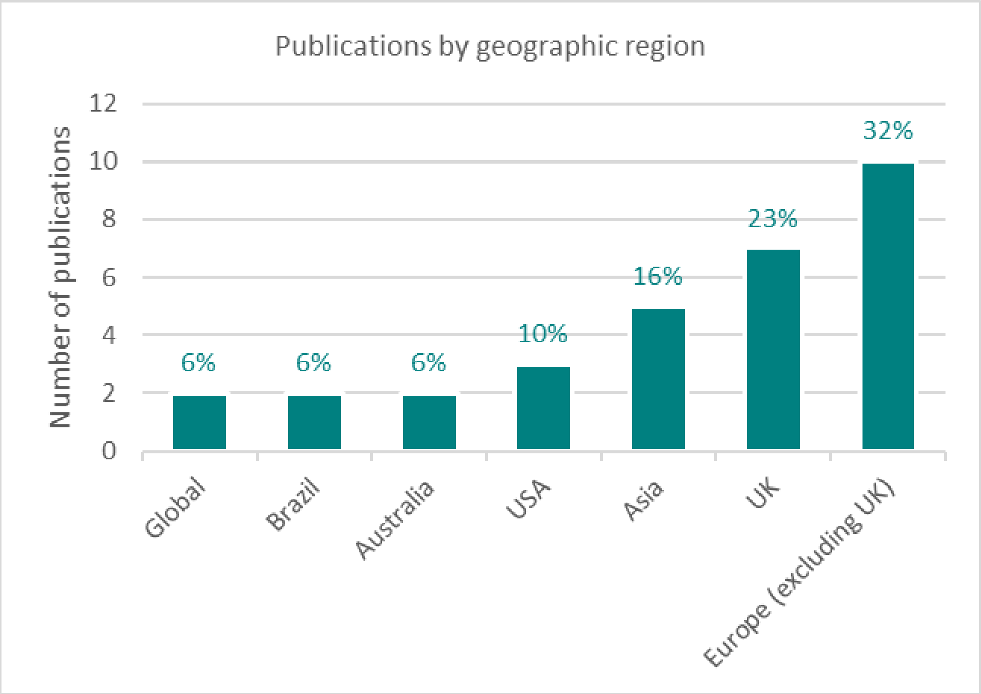


Figure 5. Literature search results grouped by geographic region. Studies originating in the UK are separated from those from the rest of Europe.

When grouped by the focus of the study (Table 3), it can be seen that much of the literature (Categories A–D) centres on bounded study areas consisting of a discrete portion of the complete water cycle. The remaining papers (Category E) consider the complexities of integrated systems and how to define goals and methods of assessment. The number of publications in this category has increased in recent years. A full list of the literature reviewed in this study is provided in Table 4.

Defining the bounds (and focus) of the study area is paramount to minimising ambiguity in the analysis. Providing clarity of inclusions and exclusions for the study or framework enables robust interpretation and transparency over how conclusions have been drawn and how they can be utilised. While focussing a study on an aspect of a larger system narrows the scope to more achievable aim(s), this should be done with cognisance of the complete system including likely consequences therein.

Table 3. Categorisation of papers.

Category	Primary Focus	Nr.	References
A—Urban systems	Urban water supply, urban storm water, urban wastewater or the urban water cycle	7	Bouziotas et al. [32]; La Rosa and Pappalardo [9]; Nikolopoulos et al. [33]; Sadr et al. [8]; Sitzenfrei et al. [34]; Sitzenfrei et al. [35]; Song et al. [36]
B—Water resources management	Management of water resources for potable water provision	6	Ahmadi et al. [37]; Gurluk and Ward [38]; Kumar et al. [39]; Piniewski et al. [40]; Tomlinson et al. [41]; Wada et al. [42]
C—Flood mitigation	Assessment of flood mitigation	4	Borris et al. [43]; de Brito et al. [44]; Goytia et al. [10]; Franco et al. [45]
D—Water quality (river)	Assessment related to river water quality	2	Crossman et al. [46]; Sultana et al. [47]
E—Non-specific aims, models and frameworks	These do not have a primary focus listed above; instead. they focus on defining the system to be investigated, the desired end goal or the method of assessment	12	Blair et al. [48]; Calvin et al. [49]; Heller et al. [50]; Howarth and Monasterolo [51]; Lawson et al. [11]; Li et al. [52]; Markolf et al. [53]; Nguyen-Viet et al. [54]; Pedde et al. [55]; Qiu et al. [56]; Xu et al. [57]; Yu and Lu [58]

Table 4. Literature search results, not including grey literature.

Record	Year	Location	Focus of Study	Method of Analysis	Timeframe or Horizon	End Goal
Ahmadi et al. [37]	2020	Iran	Water resource management	Social Choice Theory	25-year simulation	Identification of a 'best' water resource scenario based on environmental, social and economic criteria
Blair et al. [48] *	2019	UK	Generalised	'models of everywhere' concept using data from multiple sources	N/A	Modelling to increase environmental understanding of a place
Borris et al. [43]	2016	Sweden	Flood mitigation	WinSLAMM—Source Loading and Management Model for Windows	2050	Assessing the impact of stormwater treatment in future scenarios
Bouziotas et al. [32] *	2019	The Netherlands	Urban systems	UWOT (development)—The Urban Water Optioneering Tool	N/A	Simulation-based framework with key performance indicators at a neighbourhood scale
Calvin et al. [49]	2019	USA	Generalised	GCAM v5.1—Global Change Assessment Model	2100	Demonstration of links between energy, land, water, climate and economic systems
Crossman et al. [46]	2013	UK	Water quality	INCA-P—Integrated Catchment model of phosphorus dynamics	To 2060	Adherence to regulatory output
de Brito et al. [44]	2018	Germany	Flood mitigation	Multi-criteria approach for participatory flood vulnerability assessment	N/A	Individual and group flood vulnerability maps
Goytia et al. [10]	2016	England, France, Sweden, The Netherlands	Flood mitigation	N/A—assessment of regulatory frameworks across selected countries	N/A	Adaptation in national water laws

Table 4. *Cont.*

Record	Year	Location	Focus of Study	Method of Analysis	Timeframe or Horizon	End Goal
Gurluk and Ward [38]	2009	Turkey	Water resource management	Dynamic non-linear programming model	20-year projections.	Water management to consider economic efficiency, climate change and food security separately and together
Heller et al. [50]	2014	Brazil	Generalised	Participatory method	20-year horizon	Generation of strategic sanitation plan
Howarth and Monasterolo [51]	2017	UK	Generalised	Participatory/co-production method	N/A	Understanding energy-food-water nexus shocks
Kumar et al. [39]	2016	Spain	Water resource management	Participatory modelling using multi-criteria decision making and ranking method	Up to 2100	Ranking based on costs, water stress and environmental impact
La Rosa and Pappalardo [9]	2020	Sicily, Italy	Urban system	SWMM—Storm Water Management Model (US EPA)	N/A	Evaluation of SuDS in terms of flood risk mitigation and social benefits within an urban area
Lawson et al. [11]	2020	UK	Generalised	N/A	N/A	Resilience in the water sector
Li et al. [52]	2019	China	Generalised	Input-output models linked with system dynamics models	2025	Cleaner production strategies
Markolf et al. [53]	2018	USA	Generalised	N/A	N/A	Resilience across aspects of a system to prevent lock-in
Nguyen-Viet et al. [54]	2009	Vietnam, Thailand, and Cote d'Ivoire	Generalised	MFA (material flow analysis) combined with QMRA (quantitative microbial risk assessment) and PFA (pathogen flow analysis)	N/A	Formulation of critical control points, vulnerability to risk and presence of resilience
Nikolopoulos et al. [33] *	2019	The Netherlands	Urban systems	UWOT (case study)—Urban Water Optioneering Tool	25-year horizon	Resilience framework incorporating narrative futures and stress testing
Pedde et al. [55]	2021	UK	Generalised	UK specific shared socioeconomic pathways	2100	Development of narrative future scenarios
Piniewski et al. [40]	2014	Poland	Water resource management	SWAT—Soil and Water Assessment Tool High resolution data and long-term monitoring required	2050	Impact of scenarios on environmental flow requirements
Qiu et al. [56]	2018	USA	Generalised	Agro-IBIS—Agricultural version of Integrated Biosphere Simulator High resolution data and long-term monitoring required	2070	Prediction of ecosystem services over time and space
Sadr et al. [8]	2020	UK	Urban systems	Adaptation pathways	2015–2050	Decision-making with reliability, resilience and sustainability
Sitzenfrei et al. [35]	2014	Austria	Urban systems	Epanet2—software to model hydraulic and water quality behaviour of distribution systems	20-year horizon	Identification of energy generation opportunities
Sitzenfrei et al. [34]	2010	Austria	Urban systems	DynaVIBe—Dynamic Virtual Infrastructure Benchmarking	N/A	Generation of virtual case studies to feed into modelling systems

Table 4. *Cont.*

Record	Year	Location	Focus of Study	Method of Analysis	Timeframe or Horizon	End Goal
Song et al. [36]	2018	China	Urban systems	Quantitative-Dynamic linear input-output model	12-year horizon	Sustainable economic development
Sultana et al. [47]	2019	Australia	Water quality	SWAT—Soil and Water Assessment Tool HEA—Hybrid Evolutionary Algorithm GF—Gradient Forests	2045	Stream health with respect to macroinvertebrates
Tomlinson et al. [41] *	2020	UK	Water resource management	Pywr: water resource network modelling Python library Assessing multiple simulated options to identify the optimal one	N/A	Water resource network modelling
Franco et al. [45]	2018	Brazil	Flood mitigation	Social Vulnerability Index	N/A	Classification of social vulnerability with respect to floods
Wada et al. [42]	2017	N/A: Authorship widespread	Water resource management	Developments in hydrological modelling	N/A	Human impact modelling in large-scale hydrologic models
Xu et al. [57]	2015	Australia	System goals	N/A	N/A	Resilience as a framework for sustainability
Yu and Lu [58]	2018	China	Integrated systems	EKC—Environmental Kuznets Curve	N/A	Balance of economic growth and water quality in transboundary river systems

* Denotes additional sources added to database search results.

The use of water and its return to the environment can influence flow rates, temperature, and chemical composition. The impact this has on the receiving waterbody depends on the type of user, mitigating processes that are put in place and the characteristics of the waterbody itself. These effects on the holistic system can be included using specific assessment criteria encompassing parameters outside the direct field of interest, as in the cases of Ahmadi et al. [37] and Kumar et al. [39]. In a complex system, such as water catchments and groundwater, a systems approach has been noted as important for the consideration of justice [59].

The studies were found to assess various aspects of water use with little consideration of holistic sustainability or environmental justice assessments at a catchment scale. Alongside the apparent growth in interest of sustainability considerations in all aspects of infrastructure and urban service provision, the consideration of holistic sustainability or environmental justice assessments is now emerging at global scales, evidenced by the work of Calvin et al. [49], Acosta et al. [60], Jung et al. [61], Kebede et al. [62], and others. That this is not reflected at a regional or catchment scale, or within the water context, which has proved to be an unanticipated finding from the review.

5. Discussion

The literature has been reviewed to uncover thinking and practices related to the following themes: defining the end goal at strategic and intervention levels (Section 5.1), considering the future (Section 5.2) and methods of evaluation (Section 5.3).

5.1. Defining the End Goal: Resilience, Sustainability and Environmental Justice

5.1.1. Strategic Level

Sustainability as an end goal is not as well-defined as it may initially be perceived to be, given its universal profile in almost every aspect of scholarship and practice. This is possibly because sustainability in its truest form could be seen as an unachievable panacea and so multidimensional as to be an indefinable goal, leading to a focus on achieving something that is considered 'less unsustainable'. Xu et al. [57] discuss the progression of sustainability from a stable objective to an adaptive concept through the adoption of resilience thinking and proceed to highlight the variation in the definition by sector. Due to the multi-faceted functions of the water system, this is a source of potential conflict between water users. Resilience can be defined as the continuation of functionality in the face of change [63] and through current, human, terms [57]. This implies that a system could be resilient without considering intergenerational equity. However, a resilient system should be robust to externalities and therefore become a precursor to intergenerational equity and, by association, the broader aim of sustainability and environmental justice. Indeed, Lawson et al. [11] consider resilience as a path to sustainability, although, in this case, sustainability is defined as the intersection of the competing interests of maintaining supply, conserving the environment and providing a service that is not cost-prohibitive.

Adaptive governance has been posited as a means of facilitating resilience with respect to flood defence infrastructure [10] and the pursuit of desired states in terms of ecological and social outcomes. An 'adaptation pathways' approach, which assesses possible strategies to ensure the inclusion of reliability, resilience and sustainability, as well as alignment against a 'no-regrets approach', is presented in Sadr et al. [8] as a 'pipeline of strategy'. In this approach, reliability, resilience and sustainability are considered as a hierarchy that builds from one state to the next (Figure 6). There is arguably a further stage needed: one that incorporates the concepts of social equity through environmental justice and uses this as an objective of decision-making [9]. Dasgupta [64] also makes a case for the inclusion of nature into economic assessments, through the inclusion of natural capital alongside human and produced capitals and the inclusion of environmental justice as a framework for defining the end goal.

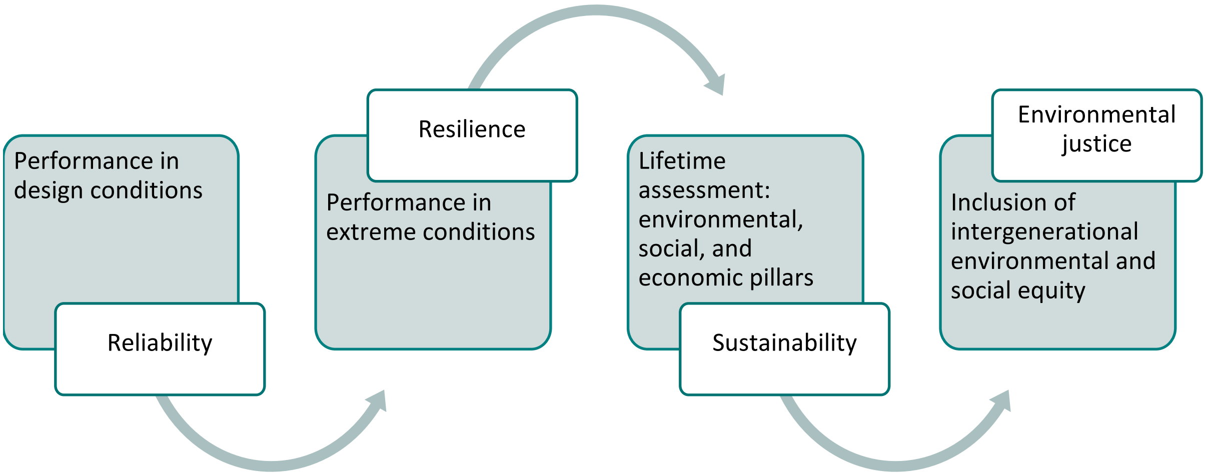


Figure 6. Hierarchy of goals in assessment methods. This diagram interprets the discussion in Sadr et al. [8] and La Rosa and Pappalardo [9].

Economic drivers are present in the assessments of Song et al. [36], Li et al. [52], Gurluk and Ward [38] and Tomlinson et al. [41] rather than social or environmental objectives. Previously, the aim of economic growth was considered ubiquitous to the extent that it underpins the 25-Year Environment Plan [27]. However, more recently, recognition of the finite nature of the planet and the incompatibility of this with conventional ideas of continuing economic growth, have called this concept into question [64,65]. As sustainability is typically defined in terms of the combination of the three pillars of economy, environment and society [5], this has implications for how success is defined. In the context of the UK water industry, economic success could be considered in a broad sense of societal economic benefit or in a constrained sense of sustainable and resilient funding [21,22,25].

Each of these has critical implications for the methods adopted and the process by which conclusions can be drawn from analyses undertaken therein.

5.1.2. Intervention Level

Strategic goals collectively frame the objectives, bounds of specific investigations and adopted interventions at a local scale. Interventions here are considered as a modification to (or input into) the catchment which ultimately impacts the water environment. For example, a positive intervention may be improved wastewater treatment to reduce nutrient levels in effluent entering the river. Likewise, a negative intervention would be one that achieves the opposite. In the development of strategic goals into local action, the perspective shift can have implications in both the definition and exploration of aims.

Constraining the focus of an investigation (in space or time) enables the assessment of a specific intervention by narrowing the assessment parameters. However, as a consequence, it simplifies interdependencies, omits consideration of wider implications, either positive or negative, and therefore consequently weakens the conclusions drawn. This approach can be seen through spatial constraints adopted in Crossman et al. [46] and Ahmadi et al. [37] and short-term assessments undertaken in Song et al. [36] and Li et al. [52].

The implications of technological interventions, when considered in isolation, particularly regarding lock-in and adaptive governance, are discussed in detail by Goytia et al. [10], Lawson et al. [11], Markolf et al. [53] and Sadr et al. [8]. This raises issues over not only the limitation of future options to further technological solutions, but also ethical considerations over who pays for these interventions, now and into the future, if the lens of sustainability and environmental justice is to be adopted.

Understanding the impacts of interventions can be complex; the impact within a geographical area is not necessarily homogenous. Franco et al. [45] highlight the need to understand vulnerability, in this case social vulnerability to flood risk, at a community-relevant level of granularity. Similarly, Qiu et al. [56] highlight the need to understand impacts on ecosystem services in both spatial and temporal contexts as they can behave in disparate ways. The combination of these studies highlights the complexity of understanding impacts and interdependencies within the water system. Assessments focusing on a subset of this complete system, or on certain attributes, risk leading to unexplored impacts on future generations.

5.1.3. Assessment Outputs

The outputs of assessments are important in the application of decision-support frameworks, including the ability to visualise options and impacts at an appropriate scale for collaborative exploration [48]. Visualisation can be used to create a common language and framework for multi-disciplinary discussion and to enable communication with a wide range of stakeholders and decision-makers. Visualisations may be in the form of immersive characteristic descriptions [2,66] alongside images, thus enabling the appreciation of personal experience and behaviours within future scenarios.

Not only are the outputs themselves important, but also how they are used and how their relative importance is weighted in combined analyses. This process is not straightforward and has consequences. For example, Gurluk and Ward [38] included environmental benefits as assessed through the willingness to pay, which could bias results towards the human experience. There is also the possibility that the implementation of interventions would vary according to the economic status of the population, leading to inequity in the distribution of interventions and the resulting benefits. If this is the case, it would limit the ability to provide interventions that work towards a goal of environmental justice.

5.2. Looking to the Future

5.2.1. Defining the Timescale

Assessment horizons need to be defined when evaluating the effectiveness of decisions into the future, since they enable (or otherwise remove the possibility of) consideration of intergenerational equity. However, the timescales used (Table 5) are specific to the focus of the investigation and can be seen to vary between 5 (insufficient for intergenerational considerations) and 35+ years.

Table 5. Timeframe for assessment (note: not all of the reviewed literature included assessments into the future).

Timeframe	Nr.	References
5–12 years	2	Song et al. [36], Li et al. [52]
20–25 years	6	Nikolopoulos et al. [33], Sitzenfrei et al. [35], Ahmadi et al. [37], Gurluk and Ward [38], Sultana et al. [47], Heller et al. [50]
35 years+ Middle to end of century	8	Sadr et al. [8], Kumar et al. [39], Piniewski et al. [40], Borris et al. [43], Crossman et al. [46], Calvin et al. [49], Pedde et al. [55], Qiu et al. [56]

5.2.2. Defining the Timescale

Sadr et al. [8] proposed that assessments should be carried out in timeframes to align with investment periods, planning or regulatory periods. This is reflected in recent guidance for adaptive planning that requires a 25-year plan with reviews aligned to price review periods [30]. Nevertheless, it would also be beneficial for predictions to encompass a complete asset life cycle. Within the context of the UK water industry, many assessments result in infrastructure investment, which can conceivably operate for many decades; indeed, in the case of network infrastructure, the asset life can extend to more than 100 years [33]. However, predictions into the future become increasingly difficult and uncertain as they progress further away from the present day. The use of statistical approaches to scenario generation [34,41], using probability functions or machine learning, is undoubtedly heavily data-reliant; the implications of this are discussed in Section 5.3.2.

The alternative is to assess interventions against a range of potential future scenarios that are rooted in socio-technological and political narratives. Examples include those proposed by Global Scenarios Group (GSG) Futures [67], Shared Socio-economic Pathways (SSPs) [68] and Urban Future methods [1], as well as approaches referred to in seven identified papers shown in Table 6.

In the case of Borris et al. [43], it is noted that even though the SSPs on which the assessment is based extend to 2100, a period extending to mid-century is used for the analysis in order to improve confidence. This is a balance that must be struck; as predictions extend further into the future, they are associated with progressively greater, and ultimately unacceptable, degrees of uncertainty (and even modest timeframes can be subject to important, sometimes unforeseen, contextual changes), and thus scenario modelling becomes important [2]. In contrast, basing decisions on near-future certainty [52] leads to increasing likelihood that investment decisions will not continue to generate the required outcomes throughout the asset life cycle.

The use of a limited number of 'models' to generate future scenarios for analysis simplifies the method and enables it to become more readily quantifiable; however, it also reduces the amount to which interdependencies can be explored and accounted for in a highly interconnected system. For example, Sitzenfrei et al. [35] develop scenarios based on expected changes and a more hypothetical future; however, the impact of variables is considered separately and, exacerbating this limitation, the combined impact of multiple factors is not discussed.

Kumar et al. [39] and Piniewski et al. [40] describe methods that generate scenarios based on varying a limited number of factors. Ofwat [30] also favours this approach and suggests that the factors should predominantly be viewed independently of each other. Conversely, Nikolopoulos et al. [33], Qiu et al. [56] and Sadr et al. [8] generated scenarios rooted in a wide range of diverse factors. Whilst this makes the analysis more complex, it also provides a richer view of future scenarios and aligns more fully with methods developed by the Global Scenarios Group and SSPs.

Table 6. Use of future scenarios.

Article	Number of Future Scenarios	Description	Horizon
Borris et al. [43]	3	Climate change and socio-economic factors using Shared Socio-economic pathways as a basis for generation: Sustainability; Security; Intermediate	2050
Kumar et al. [39]	4	Defined as water supply to three sectors Infinite nature; low, medium and high use of alternative resources	2100
Nikolopoulos et al. [33]	7	Ranging from mild to extreme; gradual rate of change and magnitude of change across a small number of parameters, and large changes across a wide range of parameters with sudden changes in some	25 years (or 2044)
Pedde et al. [55] *	5	Country specific narrative scenarios based on European Shared Socio-economic Pathways. Can be depicted on a matrix of challenges to adaptation and challenges to mitigation	2100
Piniewski et al. [40]	2	Stakeholder workshops generated two scenarios: sustainability eventually—environmentally optimistic; economy first—fast economic growth with intensive agriculture	2050
Qiu et al. [56]	4	Scenarios developed to represent social, political, economic and biophysical drivers. Accelerated innovation; abandonment and renewal; connected communities; nested watersheds	2070
Sadr et al. [8] *	4	Scenarios defined for characteristics for both society and the integrated urban wastewater systems. Market; innovation; austerity; lifestyles	2050

* Indicates the study was undertaken in the UK.

5.2.3. Future Scenarios

There is a growing body of literature regarding future scenarios. Hunt et al. [69] provide an analysis of the development of these scenarios and their alignment with GSG futures [67], suggesting an archetypal set of four extreme scenarios that avoid societal breakdown, therefore providing useful testbeds for proposed systemic interventions (i.e., New Sustainability Paradigm—NSP, Policy Reform—PR, Market Forces—MR, and Fortress World—FW). The basis of the future scenarios approach is the generation of internally consistent, extreme-yet-plausible narratives based on social, political, economic, and environmental factors [2]. As Hunt et al. [69] conclude, the wealth of research developing and utilising future scenarios is consistent within the framework developed by GSG. It is no coincidence therefore that more recent developments, such as SSPs [68] which have been used by Borris et al. [43], align with this framework. The Environment Agency has also adopted this approach in the development of scenarios for the water environment, encompassing political, socioeconomic, technical and environmental influences [66,70]. This very much embraces a STEEPO approach, i.e., consideration of Social, Technological, Economic, Environmental, Political and Organisational drivers of change. Conversely, Ofwat [30] has suggested the use of 'high' and 'low' parameters across four key areas: climate change, technology, demand and environmental ambition. These areas are considered in isolation, both as factors and with respect to either the water or wastewater systems, which runs counter to an appreciation of the interconnectedness of a holistic system.

Pedde et al. [55] aim to develop global and European SSPs into UK-specific pathways. Generally, the narratives are consistent, although in striving to incorporate UK-specific regulation and targets, some variation is introduced. In terms of economic goals, the main driver is switched from a measure of 'per capita GDP' to a broader outlook combining the nature of the economy, prosperity and well-being, with a greater emphasis on behaviours and governance influences on the economy.

5.3. Method of Evaluation

5.3.1. Making Use of Local Knowledge

Participatory approaches, in which stakeholders and experts provide the basis for assessment [10,37,39,44,50,51,57], provide benefits inherent in introducing collaboration and co-creation to the process. This integration of local knowledge acknowledges cultural influences, social factors and their inherent complexities, thereby increasing engagement and the likelihood of successful implementation. Goytia et al. [10], in particular, stress the importance of participatory techniques, not only once a pathway has been determined but throughout planning. How stakeholders are engaged in the process, how responsibilities are allocated and the length of the process are all aspects that require consideration.

Using a participatory approach can be an 'involved process' taking several years to complete as in the case of Heller et al. [50]. In this case, there is also a preference for maintaining the same individuals throughout the process. This not only affects the achievability of this approach but also exposes the conclusions to bias towards individual preferences. The authors highlight global regions where a similar approach has been advocated with varying levels of success, which may indicate cultural influences on the decision-making process that has been presented.

A stakeholder-based decision support system presented by Ahmadi et al. [37] modulates the influence of a given stakeholder in the decision-making process by the level of power and influence they hold in the governance system. This has the potential to leave decision-making open to injustice by enabling those with the most to gain or lose, namely the most vulnerable in society, not to be appropriately represented. It also does not define how to represent those without a voice, for example, natural systems or future generations. There may be opportunities to use governance systems rooted in sustainability and environmental justice to address this risk; however, this is not formally integrated into the decision-making framework.

5.3.2. Reliance on Data

The alternative to a participatory method is the use of quantitative analysis, simulation and modelling [8,9,32–36,38,40,41,43,46–49,52,54,56,58]. Additionally, Blair et al. [48] propose a combination of approaches, with quantitative modelling used to form a baseline that can then be informed and refined by local knowledge utilising participatory techniques. In cases where the focus is on water resource management, methods based on demand metrics and supply and demand modelling are frequently used [32,33,35,37–42,49]. Furthermore Hunt et al. [71] propose the use of Mass Flow Analysis (MFA) to generate potential flow rates from rainwater harvesting systems. Understandably, quantitative approaches are reliant on a substantial number of reliable data to generate predictions [40,48,56].

Existing data, in particular environmental data, are often the basis for quantitative modelling [8,36,43,46–48,52,56,58]. Whilst population and demand data can be relatively readily obtained, environmental data are disjointed and of variable quality and useability. A review by the UK Environmental Observation Framework [72] showed that 80% of environmental data collected could not be reused by others due to a lack of coordination and governance, leading to fragmented data sharing. Temporal and spatial granularity is important in assessing the impacts to a water system, in terms of both human and ecosystem effects [45,56], as well as the interpretation of results relating to interventions within the system. Uncertainty regarding regulatory data is relevant to the method proposed by Crossman et al. [46], which uses regulatory data as the input to the INCA-P model used in this analysis; however these data have become less robust in the eight years since this method was published [73].

Using historic environmental data to act as a basis for future extrapolations [30,36,46–48,52], i.e., using hindsight as a tool for foresight, assumes that the future will follow existing trends. Yet, there is substantial and growing evidence that this is not the case and step changes, extremes and uncertainty are to be expected with increased frequency [74,75].

There is frequent application of climate models in future predictions [39,40,42,46,49], although Howarth and Monasterolo [51] highlight the risk of using these models in understanding the dynamics of a complex system due to their inherent uncertainty and the multiplicative effects of combining several uncertain datasets. The uncertainty related to the use of climate models also increases as we look further into the future, limiting the horizon that can be examined.

Therefore, it is evident that there is little consensus on what data can be used, where data are available, and how they can be used in future predictions. There has, however, been some effort to mitigate the uncertainty or unavailability of environmental data [33,34,54,76]. A lack of reliable and representative data hampers the development of decision-support tools that encompass the catchment as a complete system. Consideration must be given to what are appropriate metrics, both now and into the future.

6. Conclusions

There is a growing body of research concerned with the generation of decision-making frameworks, many of which make use of scenarios as a method of identifying impacts into the future. However, the formation and application of methods are varied, spanning participatory and simulation approaches, the use of stakeholder views, simulated data and real environmental data. The formulation of methods appears to be specific to the goal that is sought as well as the cultural influence of the region in which the analysis is being deployed. There is also evidence that assessments of sustainability and environmental justice have centred on constrained local issues or have occurred at a global scale rather than at a catchment system level. Within the context of the UK water industry, the recommended consideration of uncertainty in PR24 within defined areas, and predominantly in isolation, limits the potential of futures analysis to strive towards environmental justice.

Transparency in the development of frameworks is important. This is necessary to define not only what will be explored with a defined level of accuracy and repeatability, but also what is not included in terms of bias, missing interactions and interdependencies that are unaccounted for. Similarly, a detailed exploration and definition of the study area is required, including boundaries and identification of conflicting interests. To enable this exploration, there is a need for a method of visualising catchment characteristics and interdependencies not only now but also into the future. Visualisation enables collaboration with a wider cohort, establishing a common method of communication to capture, analyse and interpret information between actors with a range of backgrounds. In doing so, this creates a platform that can be used in participatory techniques and can create a bridge between technical specialists, stakeholders and decision-makers.

Author Contributions: Conceptualization, B.M.B.; methodology, B.M.B.; validation, B.M.B.; formal analysis, B.M.B.; writing—original draft preparation, B.M.B.; writing—review and editing, D.V.L.H. and C.D.F.R.; visualization, B.M.B.; supervision, D.V.L.H. and C.D.F.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors gratefully acknowledge the financial support of the UK Engineering and Physical Sciences Research Council (EPSRC) under grants EP/R017727 (UK Collaboratorium for Research on Infrastructure and Cities Coordination Node) and EP/S016813 (Pervasive Sensing of Buried Pipes), and both EPSRC, under grant EP/R513167/1, and United Utilities for supporting the doctoral research study of the first author, of which this is a part.

Conflicts of Interest: The authors declare no conflict of interest.

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