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Visualising the surface water system: an environmental justice-led approach

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It is becoming increasingly apparent that the management, protection and utilization of water requires a place-based and systems perspective to enable complexity to be visualized and assessed. Understanding the complexity of relationships across this system enables an appreciation of impacts across social, environmental and economic perspectives. This paper explores the surface water system through an environmental justice lens, identifying key pathways which both support and inhibit movement toward environmental justice using system mapping techniques. While socio-economic systems, and the impact these have on the surface water system, are demonstrably important, these externalities are difficult to predict into the future, potentially impacting the system in a variety of ways. To address this uncertainty, future scenarios, based on the archetypes generated by the Global Scenarios Group, were developed at the surface water system scale. Exploring the impact of diverse future scenarios on the surface water system through an environmental justice lens enabled the characterization of leverage points and the formation of a conceptual model. Analysis of the conceptual model determined the existence of three feedback loops centred around circular generation, cost and value recovery, and urban development. This paper presents an approach for the development of visualizations and a conceptual model to enable evidence-based societal and environmental impacts to be analyzed through a justice lens. In doing so this creates a platform to enable cross-sectoral and cross-societal exploration of drivers and impacts using a common method of communication.

KEYWORDS

causal loop diagram, environmental justice, future scenarios, system mapping, water

1 Introduction

Water is vital for life, however, this is a resource that is inaccessible and/or of poor quality across numerous regions globally (Bell et al., 2021; Han et al., 2017; Li et al., 2019; Lozano et al., 2021; Rasiah et al., 2013; Thiebault et al., 2021; Xu and Berck, 2013). In some respects a victim of the 'tragedy of the commons', water has also been commodified through its valuation as a means of economic good (Bierkens et al., 2019; Bjornlund and Shanahan, 2015; Brown, 2006; Scheierling et al., 2006; Shi et al., 2014). Subsequently, water systems have been impacted and degraded through anthropogenic activity (Abbott et al., 2019; Bell et al., 2021).

Within the UK, the development of infrastructure since the 19th century (De Feo et al., 2014; Emsley et al., 2018; Greenwood and Hilton, 2018; Stanwell-Smith, 2010) and application of policy (Bell et al., 2021; Directive 91/271/EEC, 1991; Directive 2000/60/EC, 2000; Naden et al., 2016) has enabled the provision of potable (i.e., drinking quality) water and sanitation across the population and instigated improvements in environmental water quality both through source control and wastewater treatment. However, inland surface waters (i.e., watercourses such as lakes, rivers and canals) do not yet meet the required standards (Marcal et al., 2021). Added to this, communities are increasingly critical of the state of the natural water environment and the way water services are provided (BBC Panorama, 2023; Consumer Council for Water, 2021b; Consumer Council for Water, 2021a; Horton, 2023; Water UK, 2021). There is spatial disparity in environmental impacts, the effects on communities and their ability to influence action within the water sector. This inequity of impacts and associated power imbalance across the population can be considered an issue of (in)justice.

Whilst the standard of centralized potable water supply is equivalent across England, wastewater impacts are more inconsistent, and the price of water services shows both regional variation and disparity of impact related to affluence. Differences in weather patterns between regions in England and climate change (Botturi et al., 2020; Rizzo et al., 2020) exacerbate effects on the natural water environment. The abundance of legacy combined sewers and the increasing impact of impermeable surfaces linked to urbanization (Medupin et al., 2020) influence the probability of combined sewer overflow spills and contribute to geographic variation. Additionally, the condition and characteristics of the receiving water (i.e., the river) determine the effect of treated or untreated sewage effluent which is discharged. For example, discharges into a small chalk stream will have greater impacts than when these may occur in a large, fast flowing river. This has created both water environment spatial inequity as well as cost inequity as the investment required to address the issue is not evenly distributed across the country (Water UK, 2024).

Much of the justice literature surrounding water systems is related to the allocation, provision and distribution of water between human users, commonly referred to as water justice (Neal et al., 2014; Sultana, 2018; Zwarteveen and Boelens, 2014; Grafton and Nikolakis, 2014). There is an increasing body of academic literature that considers environmental justice within the water context (Agyeman and Evans, 2004; Agyeman et al., 2016; Canfield et al., 2023; Menton et al., 2020; Simpson et al., 2023) which is more applicable to the issues arising in England. Specifically, this body of research highlights a need for a more intersectional approach to the embedment of environmental justice principles within policy frameworks and clarity over the inclusion and definition of environmental justice themes.

The definition of environmental justice is constantly shifting (Canfield et al., 2023), possibly related to its position between grassroots movement and academic research. The following definition has been adopted within this study:

> *"equity in the distribution of environmental benefits and harms for human and other-than human beings"* (Simpson et al., 2023).

Despite the growth in interest globally into justice themes, and the evident inequity of impacts both geographically and demographically, the inclusion of justice themes remain implicit rather than explicit within UK regulation and guidance (Bowman et al., 2022; Shrimpton et al., 2021). Water and concepts of justice are wide-ranging and intersectional with multiple forms of application, there is multiplicity of water functionality across human and other -than human users as well as water being considered both a public and economic good. Therefore there is a need to investigate these intersections (Canfield et al., 2023; Rendon et al., 2021) and create transparency over the potential impacts of decisions. This is the focus of this study.

Increasingly, it is evident that water systems are impacted by Environment Agency (2023), and impact (Bauwelinck et al., 2020; Bell et al., 2008; De Petris et al., 2021), numerous activities across society. As a complex, adaptive system (CAS), surface waters exhibit properties which are emergent and non-linear, as such the relationships within these systems are not straightforward to identify. Consequently, tools to embed a systemic approach and enable cross-sectoral cooperation and communication are needed. Systems thinking is increasingly being applied to enable the inherent complexity of CASs to be assessed and facilitate comprehensive exploration of consequences. Within this approach system mapping acts as an enabler to better visualize and communicate direct and indirect impacts - through the depiction of networks as a map of cause and influence (Barbrook-Johnson and Penn, 2022). Their development provides a means of supporting systems thinking through the generation of visual prompts identifying key points of interaction. As such, systems mapping aids understanding across the surface water system. Causal loop diagrams (CLD) are a specific category of systems mapping that focus on causal connections and feedback loops within a basic structure depicted in qualitative visualizations (Guest et al., 2010). Often referred to as the 'core system engine' these diagrams are used to highlight key driving forces within the system (Barbrook-Johnson and Penn, 2022).

This study focusses on the management of surface water systems within England and the environmental justice issues that prevail. Justice considerations have been found to be implicit rather than explicit within regulations and governance systems (Bowman et al., 2022; Shrimpton et al., 2021) which has implications for the inclusion of justice in decision-making. The water sector has been responsible for approximately £10billion/year investment in water and wastewater services since 2000 (Ofwat, 2022a), therefore how this investment is directed can have considerable implications for the outcomes experiences across human and other-than human users of the water environment. Moreover, recent literature has emphasized a requirement for methods to connect biophysical research with communities including the development of environmental justice-led methods to enable inclusive discussion of the intersections across users and impacts within a water system (Canfield et al., 2023). This study has applied system approaches to characterize relationships within the water system in order to create tools to enable cross-sectoral and cross-societal discussion of investment decisions and the management of water systems. These may be applied in a generalized context to uncover systemic impacts, or at a system or subsystem level to enable inclusive discussion of location-specific outcomes. This study focuses on their application at a systemic level explored within the context of England to maintain a consistent current organizational and regulatory framework, however, the approach developed herein is applicable across many contexts. The remainder of this paper describes: use of system mapping in addressing water and justice-related concerns (Section 2 – Context: Applications of system mapping) how a justice-led framework has been used in the development of a conceptual model (Section 3 – Method); the outputs of this approach (Section 4 – Results); a discussion of the relationships which become apparent (Section 5 – Discussion) and Conclusion (Section 6 - Conclusion).

2 Context: applications of system mapping

2.1 Water systems mapping

Systems approaches have been gaining traction within water research over the past two decades with an upsurge in the last 5 years.

Particular interest has been given to the water-energy-food (WEF) nexus with exploration of the interaction and impacts across these interconnected sectors. This frequently manifests within the water sub-system as an exploration of water resource prioritization across the fields of consumption, agriculture and industry, including energy generation (Givens et al., 2018; Ioannou and Laspidou, 2022). These foci of research interest frames water as a resource rather than as a multifaceted system of its own and presents a '*people and resource*' centred approach.

CLD, as a specific application of systems approaches, can be grouped in three broad categories within water research. The first continues exploration of the WEF nexus, the second applies CLDs to specific subsystems such as dairy farms (Aikenhead et al., 2015; Paterson and Holden, 2019) and the third relates to a specific impact area of which water is one of many contributing factors (for example childhood obesity (Bolton et al., 2022) or waste mobile phones (Lu, 2020)). Therefore, the role of water as a provider of services is central to these applications. Consequently, local prioritization of services and values influences the exploration of sustainability trade-offs at project or intervention scale differently to global scales (Guest et al., 2010). This is an important consideration in the implementation of CLD at policy and governance levels as well as application within a specific geographic location.

Incorporation of local requirements to address geographical, cultural or community priorities reflects a trend for participatory techniques to dominate, as highlighted within the literature (Guest et al., 2010; Tippett, 2005), although non-participatory methods remain relevant in certain contexts including Brooke and Fenner (2023), Endo et al. (2018), Shahbazbegian and Bagheri (2010) and others. Participatory approaches enable the incorporation of multiple viewpoints, which is particularly relevant when the objective relates to resource conflict (Kotir et al., 2017; Markowska et al., 2020; Purwanto et al., 2019). However, it is subject to potential bias and its success is highly dependent on engagement with a representative array of stakeholders over a relevant timeframe (Heller et al., 2014). This last point raises the issue of how natural systems are appropriately represented without being influenced by human-motives (Costanza et al., 2017; Praskievicz, 2019; Smith, 2017). Endo et al. (2018) notes that a focus on the WEF nexus and use of an ontology approach in which system map development focussed on natural systems led to barriers in the representation of linkages to social phenomena. Hence, an impact- or outcome-driven assessment of driving forces incorporating both natural systems and social justice warrants investigation as a potential mechanism to overcome these barriers.

2.2 Justice-led systems mapping

Defining the problem statement around a current need or requirement fixes the framework within current prioritization and cultural norms. However, presently adopted systems are not leading to equitable outcomes across the population or geographically. This is despite decades of policy development and water quality improvements either at the United Kingdom (Mitchell, 2019; Warwick, 2012) or global (United Nations, 2015) scale. Consequently, there would be substantial benefits to assessment of a system at both a systemic and individual scale, including using a common foundational approach to both. The framing of this objective is critical to the outcomes it has the potential to achieve.

Within the energy context Givens et al. (2018) argues that a focus on resilience in infrastructure incorporates normative views without raising the question(s) of resilience 'for whom?' and 'of what?' Similar questions could be raised around the objective(s) of sustainability which is frequently applied throughout the literature across the WEF nexus and within the water context itself. Sustainability has a wide range of definitions (Guest et al., 2010) divided between 'strong' and 'weak' sustainability (Mavrommati et al., 2014). These definitions interpret a broad concept within cultural and societal structures that are projected forward onto future generations whilst also being assumed across the current population (i.e., the baseline). Indeed the prevailing definition of sustainable development from the United Nations Report of the World Commission on Environment and Development (1987) is caveated as requiring interpretation based on country specifics within a broad common framework. After all, sustainable development is very much about local context and local conditions (Eames et al., 2017).

The incorporation of such assumptions may manifest in the overall objectives, and what is considered to be the 'success' of interventions. As an example, Gross Domestic Product (GDP) is a commonly used measure of economic success, with increasing GDP a frequent interpretation of economic sustainability and a requirement for sustainable development (Menton et al., 2020; Roobavannan et al., 2020). However, recognition of a finite world would clash with this objective and require an alternative measure of economic activity (Bowen and Ebi, 2020; Dasgupta, 2021; Raworth, 2022). GDP itself incorporates a calculation of the monetary value of goods and services generated, hence there is a possibility, underpinned by a strong rationale, that ecosystem services would be used as a means to convert environmental and social 'goods' into monetary terms (Costanza et al., 2017; Farley and Costanza, 2010) to enable a comprehensive measure of value added. This generates a plethora of additional difficulties, not least in how to put a value to these services that is applicable across the population and represents the aspirations and values of future generations (Guest et al., 2010; Mavrommati et al., 2014). The prevailing economic theory of the time is guided and influenced by contemporary events (Caporaso and Levine, 1992; Conlin, 2018), as well as having a guiding hand in ongoing policy and behaviors (Farley et al., 2020). Although multiple views and theories can exist concurrently, one will dominate policy development and subsequent behaviors of the time. Evidence of exposure to market-driven economic theory and reduction in egalitarian behavior (Farley et al., 2020) demonstrates how closely linked policy and collective behavioral traits are. Adopting a problem-based approach which incorporates assumptions based on current contexts therefore has restrictions in the way in which the system is framed and the relationships it represents. The use of future scenarios (Environment Agency, 2017; Global Scenarios Group, 2021; Hunt et al., 2012) allows exploration of the system within a range of extreme, yet plausible external characteristics, thereby incorporating a range of socio-economic constructs into the assessment. As has been determined within the realm of urban development (Hunt et al., 2013; Leach et al., 2020; Rogers and Hunt, 2019), this would enable the exploration of relationships, outcomes and impacts across potential future generations.

An alternative approach to resilience or sustainability would be the incorporation of justice into the analysis. Justice, and specifically environmental justice, can be viewed as a development in the progression from reliability, through resilience to sustainability (Menton et al., 2020; Mitchell, 2019; Sadr et al., 2020). In considering environmental justice the impacts of the system, or interventions within the system, on social equity and ecological outcomes are highlighted. This is pivotal to the ability to consider the breadth of impacts currently experienced across the water system.

3 Method

This study uses an evidence-based approach to create visualizations which aid the communication and interrogation of impacts and relationships within the water system. The use of participatory methods to build consensus in the generation of location and impact specific system maps is prevalent in the literature (for example Kotir et al. (2017), Purwanto et al. (2019), Tippett (2005)). However, this fixes the exploration within the current context and priorities of those with representation leading to the potential introduction of bias. The alternative is to use a scientific basis to generate baseline visualizations which could be further developed through participatory processes to be location specific. These also have the advantage of facilitating exploration of common relationships and interaction points within the overall context of England surface water systems in addition to their role in place-based analysis. Validation of the approach used and iteration of outputs was facilitated through use of a focus group, a method utilized by Brooke and Fenner (2023), Endo et al. (2018), Rogers et al. (2020) and Shahbazbegian and Bagheri (2010). The formation of the focus group was intended to enable cross-sectoral challenge through the inclusion of members from diverse backgrounds. The alternative to use individuals from within the water sector in England would embed entrenched ideas of norms and practices, including the inclusion, or not, of justice themes within decision-making and consequence analysis. As the purpose of visualization development was to uncover key relationships and enable a justice-led approach it was determined that a focus group well-versed in social impacts would enhance development of baseline evidence-based system maps most appropriately.

The focus group consisted of six individuals located across Sweden, United Kingdom, United States and Canada who all have an interest in systems approaches, sustainability and social justice. Participants have combined experience across water and wastewater treatment, smart water, smart cities, innovation, disaster relief, political science, environmental science, computing, economics, industrial engineering, organization psychology and environmental stewardship. The focus group members were approached individually through a collaborative forum, Pivot Projects (http://www.pivotprojects.org), of which they are a part. Pivot Projects seek to explore ecological challenges through holistic approaches and the identification of methods to enable transformational change (Bowman et al., 2023). A diversity in experiences, specialities and geography has provided robust discussion of the research outputs unrestricted by entrenched processes and priorities. Focus group discussions were recorded, transcribed then coded for aspects of the discussion, relating to either the basis of the research, social justice and economics within the water system or future opportunities for development and implementation of the research.

To enable examination of relationships outside the current context, and in so doing elucidate the nuance of changing relationships as external factors exert different stresses onto a system a series of future scenarios were utilized. This is an established method in urban development research (Rogers, 2018; Eames et al., 2017) and within the water context [including Borris et al. (2016), Pedde et al. (2021), Sadr et al. (2020)] enabling consideration of future conditions which the system may exist within, yet are far removed from current experience. The use of future scenarios is included in Environment Agency methods (Environment Agency, 2017) and was a requirement of the most recent price review undertaken by water companies in England and Wales (Ofwat, 2022b). Within this study Global Scenarios Group (GSG) scenarios (Gallopín et al., 1997) have been adopted as they provide scenarios which are less constrained by current assumptions and contexts (Bowman et al., 2022). Additionally, the GSG scenarios constitute archetypes around which future scenario themes converge (Hunt et al., 2012).

The development of visualizations was split into three phases as shown in Figure 1 and described in the proceeding text.

Phase 1: The first phase involved the definition of key elements of environmental justice in order to frame the research processes. The system itself needs to be clearly bounded and the interactions with surrounding systems understood. Additionally, to enable an environmental justice driven exploration of the system, the meaning of environmental justice across environmental, societal and economic perspectives was clarified and defined. This incorporated an iterative process, considering the properties required to enable a thriving ecology and society within a nested view of economy, society and environment with challenge and development through focus group discussions. These consisted of a two-hour online session with a focus group and subsequent semi-structured interview with an additional individual to enable the iteration and development of system maps.

Phase 2: The second phase of research focused on the exploration of relationships within the system using an environmental justice framework and the characterization of relationships based on their outcomes with respect to environmental justice objectives within each perspective. An evidence-based approach was adopted with relationships based on cause-and-effect processes defined through academic and grey literature. The final stage in this phase was the application of future scenarios to explore key interactions within a range of potential futures. Four archetypal future scenarios (i.e., Market Forces, Policy Reform, New Sustainability Paradigm and Fortress World) have been adopted, these were first developed at the global scale by the Global Scenarios Group (Gallopín et al., 1997; Raskin et al., 2002; Raskin, 2004). Brief narratives of each are included below.

Market forces (MF)

This future scenario is characterized by GDP and market-driven policy framework with an increasing shift from industry to a service-based economy and a global private sector (Gallopín et al., 1997). There is a growing income gap and decreasing social equity both within and between countries (Hunt et al., 2012). Free market behaviors lead to a multitude of impacts including: unchecked user

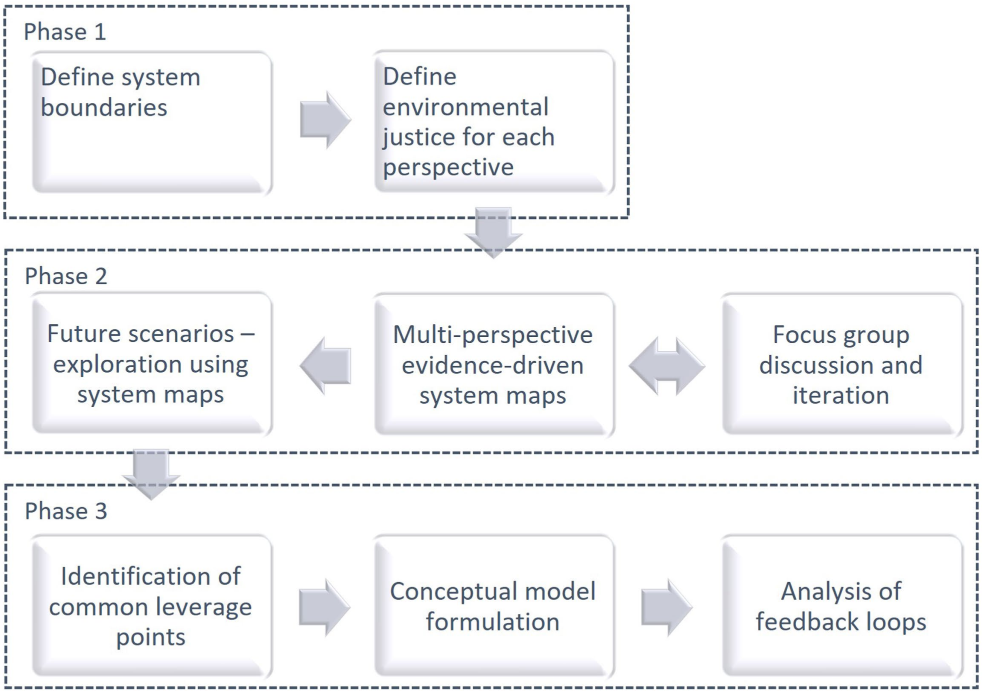

FIGURE 1
Step-wise illustration of method undertaken highlighting the three activity phases.

behavior; global environmental degradation resulting from the pursuit of product generation; growth in technology and 'Big' data (Gallopín et al., 1997) which is countered by deteriorating efficiency of technology due to free market behaviors (Hunt et al., 2012). This can be considered a society in which material consumption and growth-led governance predominate.

Policy reform (PR)

A strong policy framework, incorporating multiple forms of governance, is applied to meet social and environmental sustainability goals whilst maintaining economic growth (Gallopín et al., 1997). GDP-measured growth is a key index, however the focus on social and environmental policy increases consideration of multi-capitals and the protection of ecosystem services. Technological developments to address sustainability goals are favored over behavioral changes with global sharing of 'best practise' to meet international goals (Gallopín et al., 1997; Hunt et al., 2012). This future scenario represents a vision of sustainable development which aligns with the United Nations Report of the World Commission on Environment and Development (1987).

Fortress world (FW)

This future scenario represents a 'barbarization' as environmental and social stresses escalate. Within FW there is authoritarian rule: manifesting as an elite population within protected enclaves dominating an impoverished majority using military control to protect the lifestyle of the privileged along with access to technology and resources (Gallopín et al., 1997, Hunt et al., 2012). There is an individualistic focus with low public participation in governance due to the erosion of governance systems and community leading to social conflict, mass migration and a subsequent military response (Hunt et al., 2012). Environmental conditions worsen overall, with the export of pollution out of enclaves exacerbating a lack of infrastructure, organization and unsustainable practices (Gallopín et al., 1997, Hunt et al., 2012).

New sustainability paradigm (NSP)

The final future scenario under consideration is NSP. This represents a 'great transition' away from the historical trajectory following widespread concern and evidence of large-scale planetary shifts. Humane globalization drives a values-led change to simplicity, tranquility and community (Gallopín et al., 1997). Human well-being and the environment become central to long-term planning initiatives in communities which are engaged with policy and governance processes. Technology to enable sustainability flourishes with global transfer of innovation, the positive environmental impacts of this are supported by voluntary changes to user behaviors and the adoption of material sufficiency as a preferred lifestyle (Gallopín et al., 1997, Hunt et al., 2012).

The objective of Phase 2 was to generate comprehensive system maps which were evidence-based and perspective-driven within an overarching framework of environmental justice. These act as the basis for more focused visualizations which can be analyzed with integrity. Visualizations have been developed in Kumu (kumu.io), a system mapping platform which enables the generation of interactive, open-access visuals (Arena and Li, 2018; Mccullough, 2019; Pedersen Zari and Hecht, 2019).

Phase 3: The third, and final, research phase identified key points of interaction based on pathways to impacts across future scenarios. Within each future scenario the key impacts were identified, the pathways leading to these impacts were analyzed and the driving forces operating therein identified. These formed the basis of the development of a causal loop diagram which can act as a conceptual model of the defined water system at a systemic level as it relates to environmental justice outcomes. Feedback loops and leverage points within the conceptual model provide insights into how interventions impact across the system. [A feedback loop occurs when a change in something ultimately comes back to cause a further change in the same thing; this could further the effect (reinforcing) or limit it (balancing). A leverage point is a place in a system's structure where a solution element, or intervention, can be applied]. Validation of the conceptual model was carried out through testing the model against known effects of pricing mechanisms that position water as an economic good.

4 Results

4.1 Definitions

The natural water cycle extends through groundwater, river, sea and atmospheric phases; however, human activity has extended this natural water cycle into one that incorporates consumptive and non-consumptive uses, modification (i.e., changing composition in temperature or in chemical or biological components), transport and treatment (as summarized in Figure 2) in addition to physical changes to the water system itself. The water system therefore interacts closely with soil, geology, atmospheric and technological systems and has direct impacts on public health, habitat provision and biodiversity as well as the generation of food, energy and products. Systems thinking requires a bounded system so that internalities and externalities can be identified, however it cannot ignore inter-relationships and interactions with adjacent systems. For this study a place-based approach is adopted with the system defined as surface waters extending from headwaters to transitional areas, including lakes and wetlands. This incorporates utilization and consumption activities as indicated by red text within Figure 2.

As previously discussed, there is some ambiguity in the application of sustainability as a goal and the potential for environmental requirements to be biased through use of a human-lens in the definition of sustainability 'success'. Alternatively, an objective of environmental justice is explored. This term requires definition in the context of the perspectives included within this study. In general, environmental justice has been coined as a term to represent a specific form of justice in which social and environmental equity are prioritized (Agyeman et al., 2016; Menton et al., 2020; Mitchell, 2019; Neal et al., 2016; Neal et al., 2014; Simpson et al., 2023). This concept has been developed to articulate the properties required to enable a thriving ecology and society within a nested view of economy, society and environment. Taking an overarching definition from Simpson et al. (2023) this has been expanded through an iterative process, incorporating discussions within the focus group.

The **Economy** can be viewed at the macro-level as a theoretical framework of societal aspirations and policy as they relate to goods, services and monetary transactions. At the micro-level the flow of finances and impacts of financial instruments predominate. As such, adopting an economic perspective for the definition of environmental justice has been refined to a state in which prosperity is achieved across the nation with affordable and equitable funding of water services which can be sustained into the future. **Society,** within which the economy sits, has direct interactions with the water system and therefore requirements for its ability to thrive under a definition of environmental justice. This can be summarized as the delivery of equitable public health outcomes through water and sanitation services for current and future generations. The **Environment** is an enabler of societal functionality and well-being, although there are additional independent requirements for the environment to thrive under a definition of environmental justice. As such, a technological response to maintaining or substituting ecosystem services is not sufficient. Therefore, an environmentally just outcome is one in which non-human living organisms in the ecosystem are biodiverse, resilient and can be sustained into the future.

These definitions of ambition within each perspective from an environmental justice lens serve as the focus for examining and characterising relationships within system maps. They form a framing for the generation of more specific, targeted definitions which would be specific to the local context and conditions in the development of location-specific system maps.

The incorporation of social justice within system mapping was supported by the focus group due to the prevalence of social justice issues across their combined experience, as illustrated in the focus group workshop quotes below:

> *"we see that* [social justice] *with disaster resilience over and over and over again, the people that live in the most dangerous places tend to have fewer resources. They are less able to make those homes and lives more resilient... That is probably true with water management in different places as well. You've got this equity issue shot right through the whole thing. ...It affects different social groups in different ways."* - Focus group member A.
>
> *"it was social equity, or lack thereof, that led to the situation that exists in the first place. Populations are unequal because they are unequal. They have a hard time arguing for equality and winning that argument."* - Focus group member A.

4.2 Perspective-driven, evidence-based system maps

Examining the surface water system from multiple perspectives enables a wide range of connections, relationships and interdependencies to become apparent. However, it is when these are viewed through a lens of whether they are supportive or destructive to the goal of environmental justice that the impacts across the surface water system become more evident. Furthermore, focus group discussions supported the concept of visualizations as a means to provoke change, for example it was stated by the focus group that:

> *"In science all the major breakthroughs are when you get the telescope, the microscope, the MRI scan etc that do visualisations*

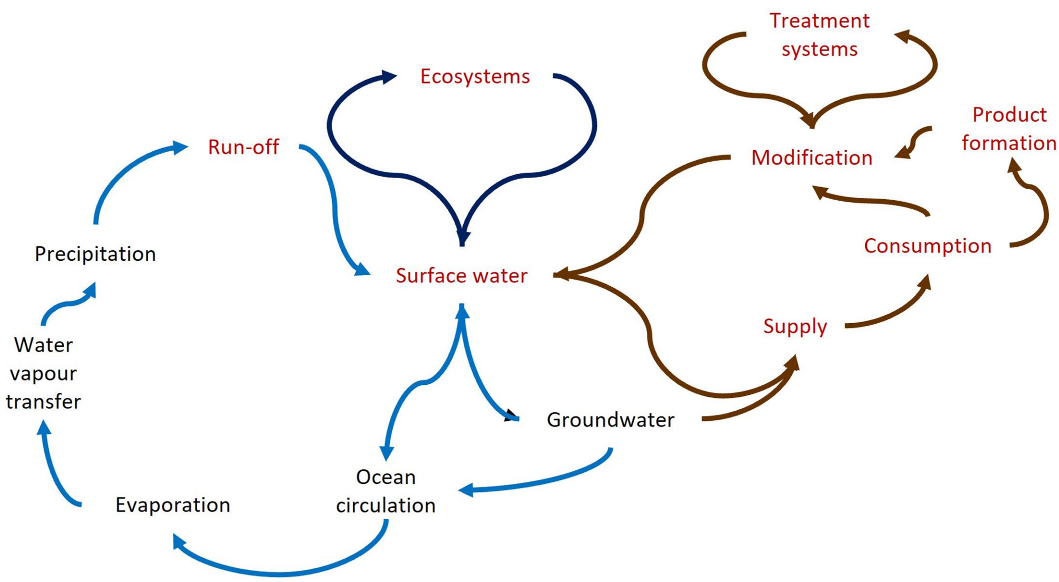

FIGURE 2
Water system. Light blue arrows represent hydrologic cycle, dark blue arrows represent interactions with ecosystems and brown arrows indicate impacts of anthropogenic activity on water systems. Red text highlights the system of interest within this study.

> *and you can see information in ways you have never seen before.”* - Focus group member B.
>
> *“By visualising it you create this, new space on the wall that enables people to understand how a system works and invent new solutions …. So there's lots of systemic solutions like that …hidden because you cannot visualize what's going on.”* - Focus group member B.

…as well as enable cross-sector collaboration which may not be forthcoming:

> *“administration boundaries almost never coincide with hydrological boundaries…. Therefore, like it or not, the multiple agencies have to collaborate which is not something they do naturally…* [leading to] *a huge concern for social equity”* - Focus group member A.

System maps were developed in this study for each of the environmental, social and economic perspectives (Figures 3–5 respectively), these branch through cause-and-effect relationships from the central, environmental justice aspiration. The system maps are most clearly viewed within Kumu itself, a presentation exploring the visualizations is available at https://BryonyB.kumu.io/exploring-the-surface-water-system?token=kb7meDvBx8THjtQ8. The branches contain linked activities, policies and characteristics; however, to make them legible cross-connections have been excluded from the system maps. Pathways that would be considered supportive (shown as solid lines) are those that enable, for example, society to thrive - through water and sanitation infrastructure that enables public health to be ensured across society equitably (Assmuth et al., 2017; Dushkova et al., 2021; Mashhoodi, 2021), illustrated in the ‘healthy environment’ branch of Figure 4, highlighting the roles of infrastructure and equity of access in enabling justice-led outcomes. Conversely, extreme rainfall events, whose frequency is exacerbated by climate change (IPCC, 2021) and urbanization increasing impermeable surfaces increases the likelihood of pathogens entering the water system either through agricultural run-off or limitations in capacity of sewage infrastructure (Mills et al., 2018; Whitehead et al., 2016). This is illustrated in the ‘public health’ branch of Figure 4 depicting routes for pathogens within the system and highlighting a potential destructive pathway (shown as dashed lines) which limits society's ability to thrive. The depiction of these networks of relationships illustrates the influences that shift the balance of the system to be either supportive or destructive toward the objective of environmental justice.

The effect on these three perspectives is further explored through the application of the four archetype future scenarios outlined in Section 3.0. These have been expanded using a society-technology-environment-economy-policy (STEEP) drivers' framework to ascertain how they would manifest at the surface water system scale within England. A brief discussion of the key impacts follows herein, a full exploration of the impacts of future scenarios will be discussed in a forthcoming paper.

At a system level, the impact of policy and societal structures on water system decisions can be understood to have impacts across both society and the environment. Market Forces (MF) and Policy Reform (PR) future scenarios are considered to be those more closely related to the current situation, which, even in these more extreme scenarios would not require a drastic shift from current norms (Global Scenarios Group, 2021; Hunt et al., 2012). As such there is an interplay between relationships that support and restrict the ability to thrive under the defined goal of environmental justice for each perspective.

A market-driven approach to policy, as seen in a MF future would place the natural environment as a provider of ecosystem services for the supply of goods and services to enable individual gain. The focus on private ownership of assets for water infrastructure prioritises monetary value, in particular low costs to customers and profit generation for individuals as accumulated wealth. Global events and climate change impact the provision of services through capability and cost. This is exacerbated by localized interpretation of environmental

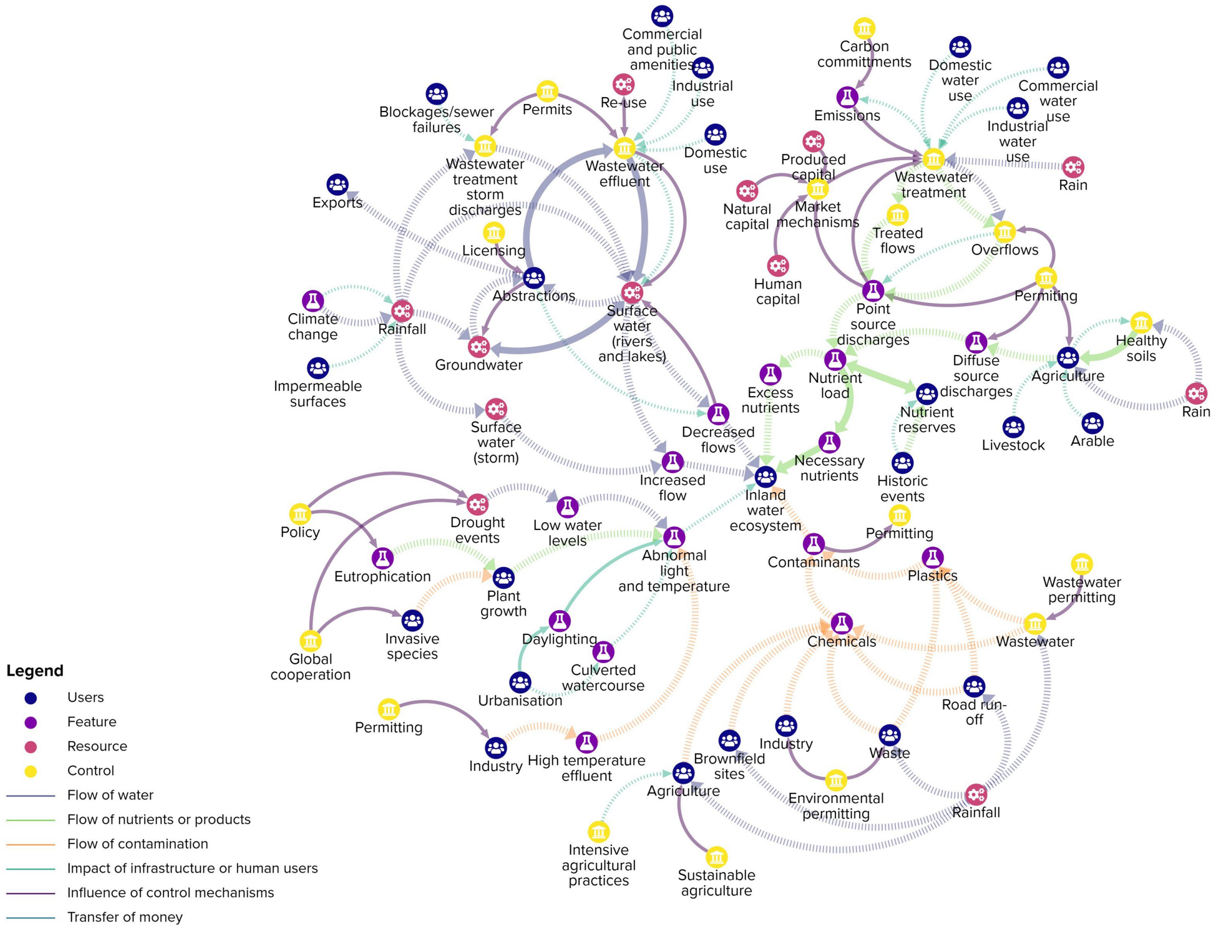

FIGURE 3
Environmental perspective system map with supportive relationships depicted as solid lines, and destructive relationships shown as dashed lines.

regulation resulting in inconsistency in both water quality and public health. Insufficient capacity, treatment and a proliferation of uncontrolled sources result in environmental degradation. There is a strengthening of those relationships that do not support environmentally just outcomes, although some mitigation is present in carbon commitments and market mechanisms to maintain ecosystem services provision. Within the societal perspective, regulation and existing infrastructure standards provide a framework, however this is undermined by behavioral trends and decreasing resilience. Overall, an increasing risk of pathogens in the environment and urban development trends result in restrictions to physical and mental health across society.

Alternatively in a PR scenario, policy mechanisms employ a command-and-control approach to ensure economic growth occurs alongside natural capital growth and the eradication of poverty. Therefore, monetary value is prioritized, however this is tempered by policy structures concerning planetary boundaries providing a trade-off between policy and profit generation. Global stability enables stringent, nationally applied regulation to ensure consistency of water quality supported by technological approaches. Funded through a balance of public and private sources this results in an accumulation of wealth within private individuals although social policy constructs ensure that payment protection measures are in place. There is a strong role of policy in strengthening relationships which are supportive to environmentally just outcomes however economic activity, and a drive for economic growth results in detrimental relationships persisting. Similarly, social equity driven policy mechanisms provide strong support for socially just outcomes as can be seen in the strengthening of relationships around physical and mental health, equity and water quality standards.

Looking at future scenarios which are more divorced from the current situation the impacts become more extreme. In a Fortress World (FW) future scenario a breakdown of social structures has led to the development of enclaves with very different outcomes. Within rich enclaves technology is used to separate people from environmental harm resulting in local protection of public health outcomes, however technology development is primarily focused on the protection of private interests through military responses to local and global threats. Outside of the enclaves environmental degradation and public health risks are rife as water and wastewater infrastructure failures proliferate driven by a breakdown in governance structures. The societal impacts of this are mixed based on societal sector increasing the inequity experienced throughout the population.

In contrast a New Sustainability Paradigm (NSP) future scenario represents a focus on planetary boundaries within a regenerative and distributive economy. Payment for water and wastewater

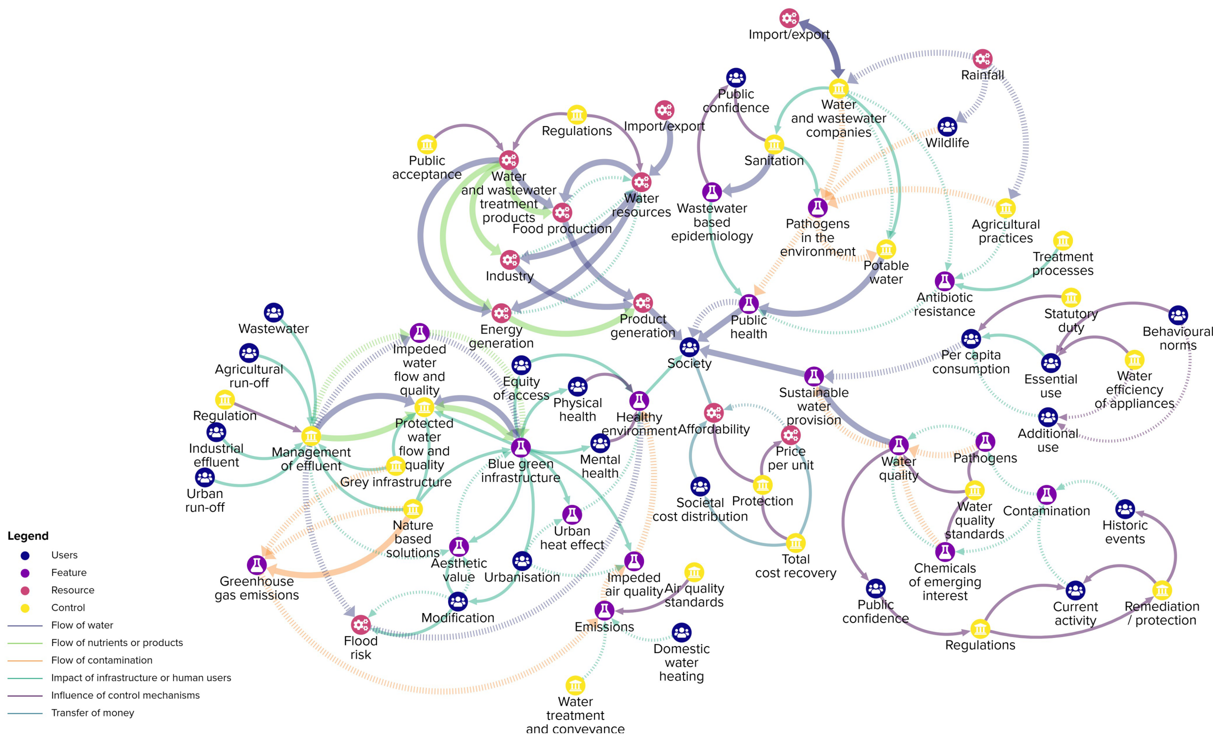

FIGURE 4
Societal perspective system map with supportive relationships depicted as solid lines, and destructive relationships shown as dashed lines.

services is equitably distributed with payment protections and social dividends in place, this is supported by global agreements over greenhouse gas emissions and virtual water as well as stringent, nationally consistent environmental regulations. There is clear strengthening of regulation, policy and interventions to enable environmental protection. This is mirrored from a societal perspective, where a combination of behaviors along with policy and infrastructure mechanisms enable equitable mental and physical health outcomes.

4.3 Causal loop diagrams

System maps represent a detailed view of relationships, retaining the inherent complexity within the system, therefore they are a valuable starting point to explore the range of interactions within the surface water system. In particular, they form a valuable common starting point for the development of location-specific system maps incorporating local knowledge and supporting multi-perspective and cross-sectoral discussion. However, they may be classed as 'horrendograms', a term coined in response to the generation of overwhelming visualizations that provide intractable insights (Barbrook-Johnson and Penn, 2022). They are dense in information to the extent that the knowledge that may be gleaned from them is obscured. This view was supported in focus group discussion of the completeness of system maps, as shown in the following quotes:

> *"I'd say the instant reaction is, they are too complete. You've got too many variables there to tease out the major differences, I would have thought. …but that's just an instant reaction."* - Focus group member A.

> *"…there are a lot of variables there…I do not think there are necessarily too many, because the world's a complex place, but depending on who you need to explain it to you may need to simplify."* - Focus group member D.

Analysis of the impacts across four future scenarios identified key pathways. Within these pathways there were a range of determining factors, four common leverage points (which are influenced by hard and soft governance systems) and a range of associated impacts (Figure 6).

These key leverage points (product generation, treatment capacity and capability, cost recovery and urban development) became the central points in the development of a causal loop diagram (Figure 7) that would depict the most influential causative relationships and could be used effectively to illustrate and analyze the system at a systemic level. Figure 7A shows the complete conceptual model consisting of interconnected loops relating to product generation (Figure 7B), urban development (Figure 7C) and value and cost recovery (Figure 7D) Central to the conceptual model are relationships associated with behaviors, attitudes and policies that closely relate to social justice issues and reflect the impact human interaction has on the natural water system.

This model was validated through consideration of a scenario in which pricing mechanisms based on water as an economic good were implemented and compared to impacts in England since privatization, the structuring of which positions water as an economic good. This

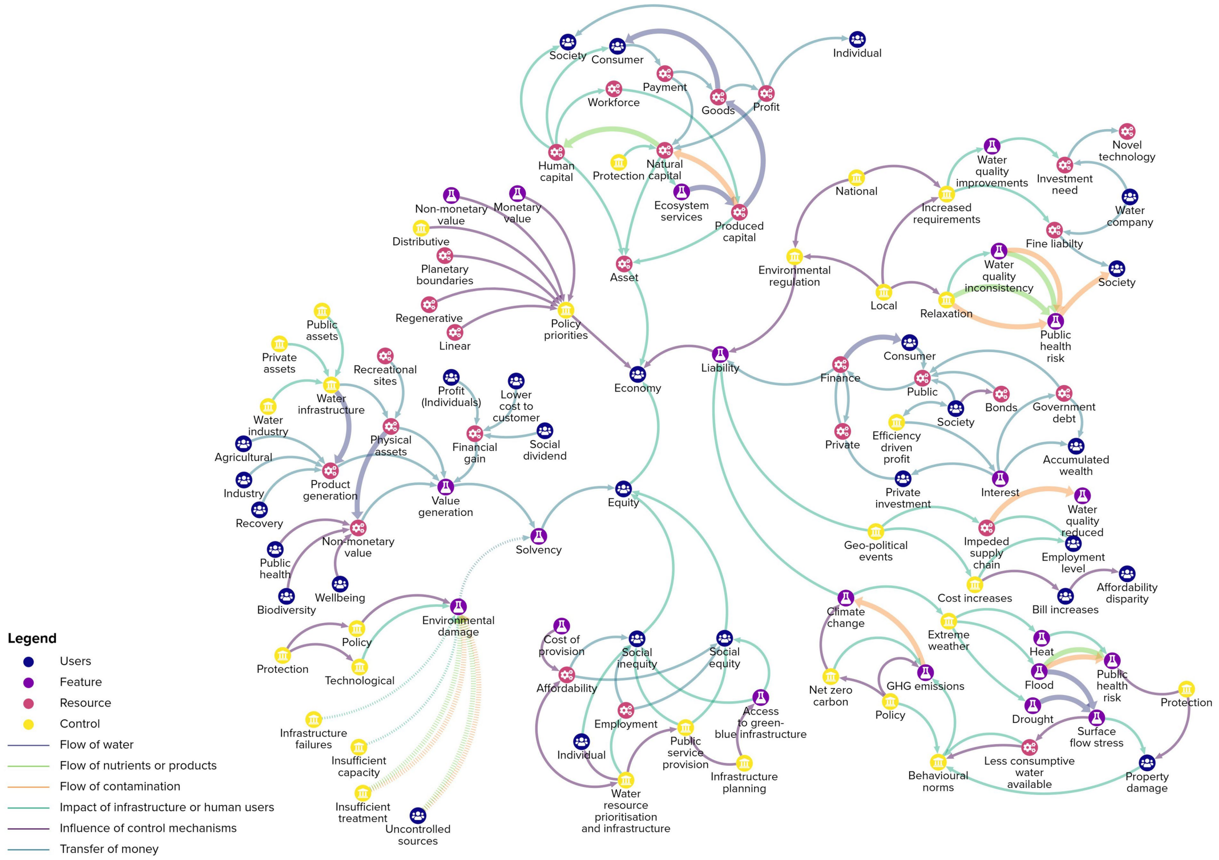

FIGURE 5
Economic perspective system map with supportive relationships depicted as solid lines, and destructive relationships shown as dashed lines.

increased influence of the 'value: economic good' node which has two paths of impact each discussed in turn. Firstly, it causes an increase in a focus on private interests and individualistic tendencies. This leads to a decrease in social trust and social cooperation and subsequently a decrease in the equitability of cost recovery. This impact accelerates decreasing social trust and increases the degree of focus on private interests. Considering the second path; an increase in influence of economic good decreases urban development with a focus on environmental and social outcomes with impacts to the capacity and capability of water and wastewater infrastructure. This leads to reductions in the removal of nutrients, contaminants and pathogens with subsequent impacts on public health, ecosystem resilience and biodiversity. Ultimately decreasing public satisfaction, social cooperation, social trust and further decreasing the degree to which urban redevelopment is focused on social and environmental outcomes. The connections between 'nutrient, pathogen and contaminant removal' and 'ecosystem resilience and biodiversity', and 'public satisfaction and 'social cooperation' show a delay as these are not immediate effects. Additionally, a decrease in public satisfaction has the potential to result in combined action to influence changes in governance mechanisms if sufficient levels of public engagement and agency can be fostered.

Examining water service provision in England demonstrates the impacts of privatization leading to prioritisation of the economic good water provides, ultimately leading to decreasing equity in cost impacts (Consumer Council for Water, 2021a). Financializaton mechanisms have increased the focus on profit generation and biased investment decisions to capital investment over operational expenditure with impacts on long-term performance (Bayliss, 2014). Additionally individualistic behaviors have driven the adoption of metering by a sub-set of the population resulting in increased costs to those least able to afford it (Bayliss, 2014; Weber et al., 2019). This mimics the relationships represented by the conceptual model as prioritization of the value of water as an economic good reduces a focus on social and environmental outcomes in preference for private interests. This in turn reduces the ability of water services to perform to expected standards with impacts across public health and ecosystems (BBC Panorama, 2023; Horton, 2023), ultimately leading to decreasing public satisfaction and trust (Consumer Council for Water, 2021b) with impacts to acceptance of water consumption reduction measures (Consumer Council for Water, 2022). These real-world impacts match the effects represented by the conceptual model providing confidence that the key drivers within the system have been captured and appropriately represented.

5 Discussion

The application of system mapping, be it evidence-based or through participatory methods, must recognize that the resultant

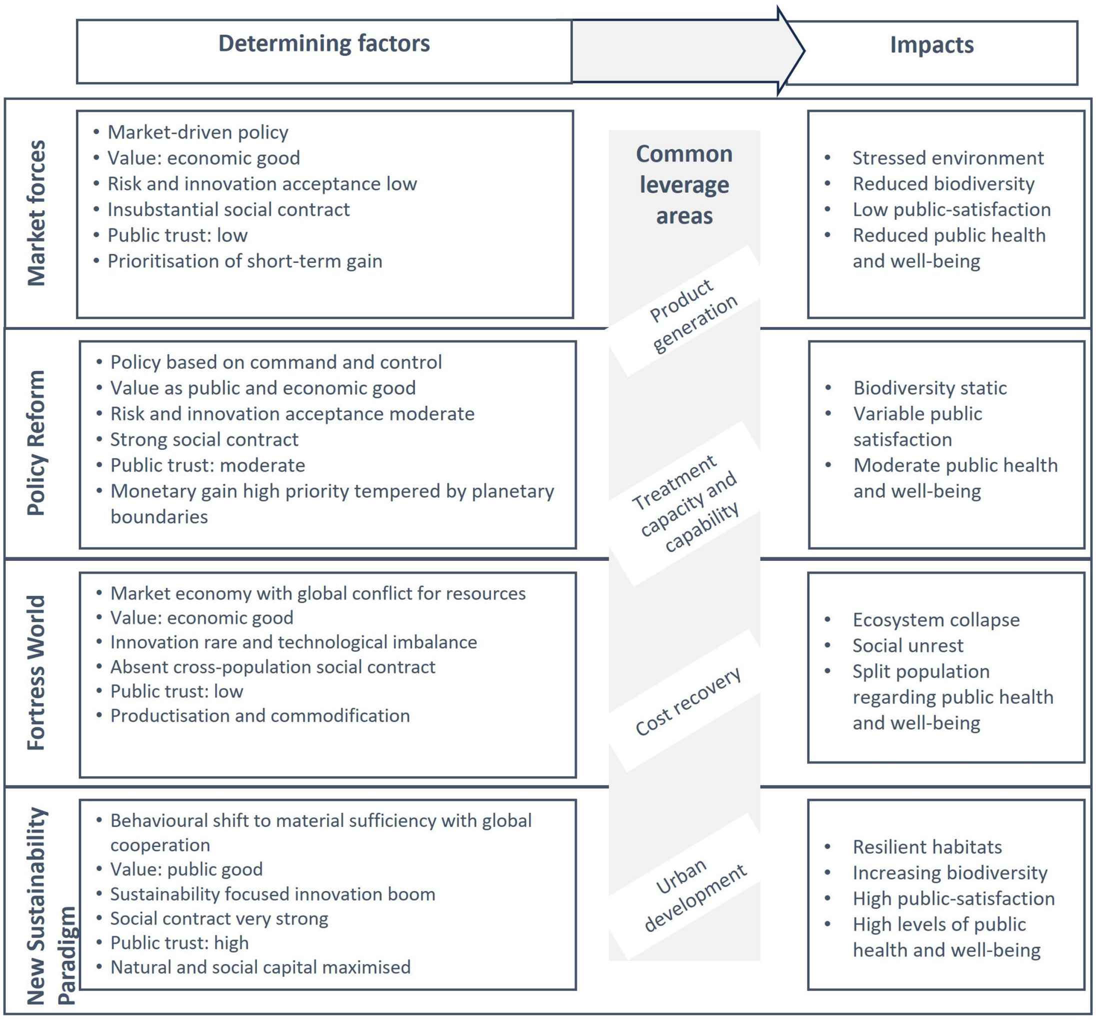

FIGURE 6
Impact chains demonstrating key leverage points across four future scenarios.

system maps can only represent current knowledge, and as such they should be continuously developed and updated. For example, the current understanding of the impacts and removal of persistent organic pollutants and microplastics is emerging (Brammer et al., 2018; Duis and Coors, 2016; Onoja et al., 2022) meaning the 'unknown unknowns' remain unaccounted for.

The development of system maps demonstrates the importance of stormwater management across the realms of both society and the environment (Figures 3–5). This may reflect growing concerns across the UK water sector leading to an increase in academic and grey literature on this topic. However, system maps evidence this causal relationship and help identify increasing risks as the impacts of climate change become more apparent, with varying levels of impacts seen as alternative futures unfold. The impact of nature-based-solutions in eliciting direct and indirect societal benefits is also clearly represented. It is possible that a hard-engineering, technological approach could achieve similar impacts; however, the equity impacts of this are likely to be damaging across social justice outcomes and require extensive controls to manage both now and into the future, due to the risks of technological lock-in (Goytia et al., 2016; Lawson et al., 2020; Markolf et al., 2018; Sadr et al., 2020). This is demonstrated through the system maps enabling communications of this issue.

Four central relationships were identified: product generation; treatment capacity and capability; cost recovery; and urban development. Each were shown to be influenced in different ways by drivers of policy, attitudes and behaviors (Figure 6). The impacts are ultimately governed by either hard or soft governance, the latter including the incumbent attitudes and behaviors of society which are a product of cultural evolution (Farley et al., 2020). This can be summarized as the tripartite interaction between value, social norms and technology. Future scenarios depict alternatives based on the response to widespread disrupting events which change the nature of society despite cultural evolution. However, once the change is enacted attitudes, behaviors and governance systems become entrenched, meaning that interventions need to operate across potential futures rather than in spite of them. This is exemplified through experiences in both Australia and United States: water use reduction was successfully achieved in response to the Millenium Drought in Australia; however the inelasticity of water consumption behavior has led to a gradual return in consumption levels as the risk

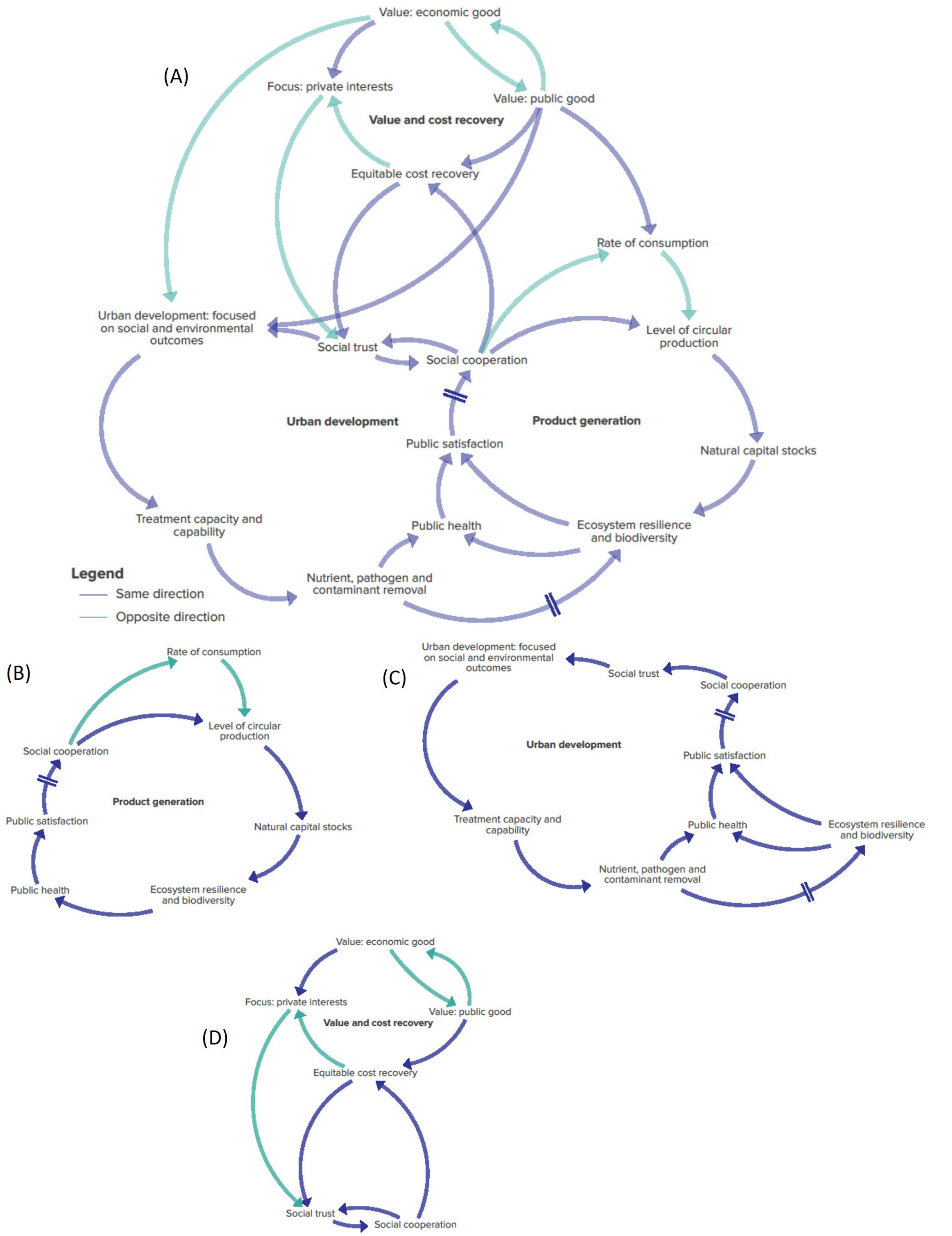

FIGURE 7
Conceptual model **(A)** with three loops isolated product generation loop **(B)**, urban development loop **(C)**, value and cost recovery loop **(D)**.

has abated (Rogers et al., 2020). This was echoed within focus group discussions:

"...the worst thing that could have happened for water management in California was the wet winter we just had [2022/23]. *Because*

> *people will think the problem's fixed, and they'll go back to their old attitudes because we had the one of one of the wettest winters ever."*
> - Focus group member A.

These examples demonstrate the recalcitrance of behaviors and the tendency to return to those which are embedded (Russell and Knoeri, 2019). Disruptive events can however lead to lasting changes, many historical examples demonstrate changing socio-economic and technological systems increasing water impacts (Ahmad et al., 2021; De Feo et al., 2014; Li et al., 2019), although decreases have also been observed (James et al., 2023; Radcliffe and Page, 2020). An interplay can be said to develop between policy and behavior due to the nature of societal behavior as a product of the prevailing culture, policy and norms. This is pertinent when interventions seek to embed new policy or behavior.

Analysing the four key determining factors through the development of a conceptual model has focused on three central, interconnected loops, these are discussed in turn below. Attitudes and behaviors, i.e., social norms, and value systems, form a pivotal role in driving and perpetuating these behaviors; this is unsurprising given the influence of human activity on the natural water cycle (Figure 2 and Abbott et al. (2019)). However, this does not reflect the current policy and intervention approach, which has a technological and asset-centric approach to environmental interventions (United Utilities, 2020).

5.1 Product generation loop

A reinforcing, virtuous loop (Figure 7B) forms between circular production, ecosystem resilience and biodiversity, public health, satisfaction and social cooperation. Increasing social cooperation leads to greater levels of egalitarian behavior and an increasing tendency to adopt behaviors which reflect finite resources thereby reducing consumption and increasing circular production practises (James et al., 2023, Radcliffe and Page, 2020). The subsequent reduction in resource consumption reduces stress applied to natural systems and is associated with proactive protection; this results in positive impacts on ecosystem resilience and biodiversity. Public health improvements are observed, which provide a positive feedback relationship reinforcing egalitarian attitudes and behavior through the observation of the impacts of previous choices. The rate of both direct and indirect consumption links as an additive function: as social cooperation increases, awareness of finite resources would lead to decreasing consumption, further favoring circular processes over linear processes. Therefore, the consumption rate exacerbates the reinforcing feedback loop.

5.2 Urban development loop

If we consider the impacts of urban development that encompass water resources, stormwater management, treatment capacity and treatment capability, a reinforcing virtuous loop (Figure 7C) forms where strong and increasing social cooperation and trust lead to socially and environmentally driven urban development (James et al., 2023). This increases the rate of nutrient, pathogen and contaminant removal which, through direct and delayed responses, increases public health and ecosystem resilience and biodiversity, respectively. Leading to increased public satisfaction, this reinforces and further strengthens social cooperation and trust. The strength of reinforcement that results may, however, be partially or completely undermined by the degree of disconnection between individual and societal action and the resulting impacts due to time delays in the realization of impacts.

5.3 Value and cost recovery loop

A negatively correlated balance between value as either an economic or a public good results in shifts between two loops (Figure 7D). The first of these is reinforced by policy and processes based on value as a public good which supports social trust and cooperation (Skewes and Nockur, 2023). Conversely value as an economic good increases the focus on furthering private interests, thus decreasing equitability of cost recovery and in so doing decreasing social trust and cooperation. As equitable cost recovery decreases, the focus on private interests increases as society tends toward less egalitarian attitudes and behaviors (Ramalingam and Stoddard, 2024). How this balance of values manifests through organizational systems, however, is likely to be on a spectrum from private industry to public services and impacted by previous societal structures. Therefore, understanding the relational impacts of the extremes can demonstrate the multifaceted impacts of policy decisions.

The value of water as a public good feeds into the 'product generation loop'; a function of the 'tragedy of the commons', this would indicate that as water is considered public its use and overuse predominates (Conlin, 2018; Shi et al., 2014). Therefore, consideration of water as a public good, and associated policy structures, are not sufficient to counter overconsumption and deterioration of the natural environment. Cognisance of the wider implications, and cross-connections enabled by system mapping and causal loop diagrams, is required to limit the risk of dis-benefits.

5.4 Illustrative example

The conceptual model includes three reinforcing loops which each include innovation as a common means to create either incremental or transformational shifts. Considering a particular policy intervention, such as nutrient recovery and recycling, enables the interactions within the conceptual model to be interrogated. A regulatory drive toward nutrient recovery and recycling would direct the adoption of technologies and stimulate acceptance within the market. This would drive the product generation cycle through positive feedback, it would also drive the urban development cycle by increasing nutrient removal and therefore public satisfaction and social trust, i.e., the system is showing benefits. In terms of value and cost recovery, providing an additional income stream enables affordability however also positions water services as a source of products reflecting its duplicity as a provider of public and economic good. Additional governance instruments would become required to ensure cost recovery is equitable.

The perspective-driven system maps can be used to explore and illustrate justice implications across human and other-than human users of the system (Figure 8). Other-than human users, as depicted

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within the environmental system map (highlighted as A within Figure 8), benefit from wastewater management which reduces nutrient loads into the watercourse. However, there are implications for carbon emissions related to nutrient recovery and impact of nutrient release from diffuse sources following the use of recovered nutrients which require investigation.

From the perspective of human users, protected water quality enables the resilience and enhancement of blue-green infrastructure with the consequential benefits in mental and physical health of a healthy lived environment. Additionally, affordability has the potential to improve as the benefits of a supplementary revenue stream are incorporated into water company finances. There are also ramifications for the provision of a more resilient food production system due to lower reliance on fertilizer imports (highlighted as B within Figure 8).

An economic perspective yields an understanding of risk and solvency of water and wastewater services at an organizational level (highlighted as C within Figure 8). The system map demonstrates the connection between protection of natural capital and provision of a more resilience asset base. Whilst increasing levels of regulation increases liability, there is also an improvement in solvency through decreases in the level of environmental harm whilst increasing the potential for value generation, with value encompassing both financial value and wider values to human and other-than human users. Overall, these impacts strengthen the relationships associated with environmentally just outcomes. However, these impacts need to be supported by equitable distributions of cost recovery and nutrient recovery and reuse activity to ensure this is achieved at a local scale as well as regional or national scales.

6 Conclusion

Inland surface water systems are impacted by human activity through the consideration of water as a resource, a source of ecosystem services and a disposal route for wastewater following consumption in domestic, municipal, industrial and agricultural settings. Existing approaches within the United Kingdom are not resulting in water services or outcomes which meet either environmental requirements or public expectations. An evidence-based exploration of relationships within the water system from environmental, societal and economic perspectives has yielded system maps that form the basis for further analysis. These visualizations were found to support discussion of environmental justice-led outcomes within a focus group. The system maps demonstrated interconnection between social justice and natural systems, reinforcing the premise that these spheres of outcomes should be considered together. Moreover, the system maps enable consideration of environmental justice through evidence-based and perspective-driven assessment of human and other-than human impacts. Thereby enhancing application of environmental justice concepts within decision-making.

Analysis of future scenarios using system maps demonstrates the range of potential outcomes and the policy, regulation and behavioral links driving these shifting impacts, in particular the influence of

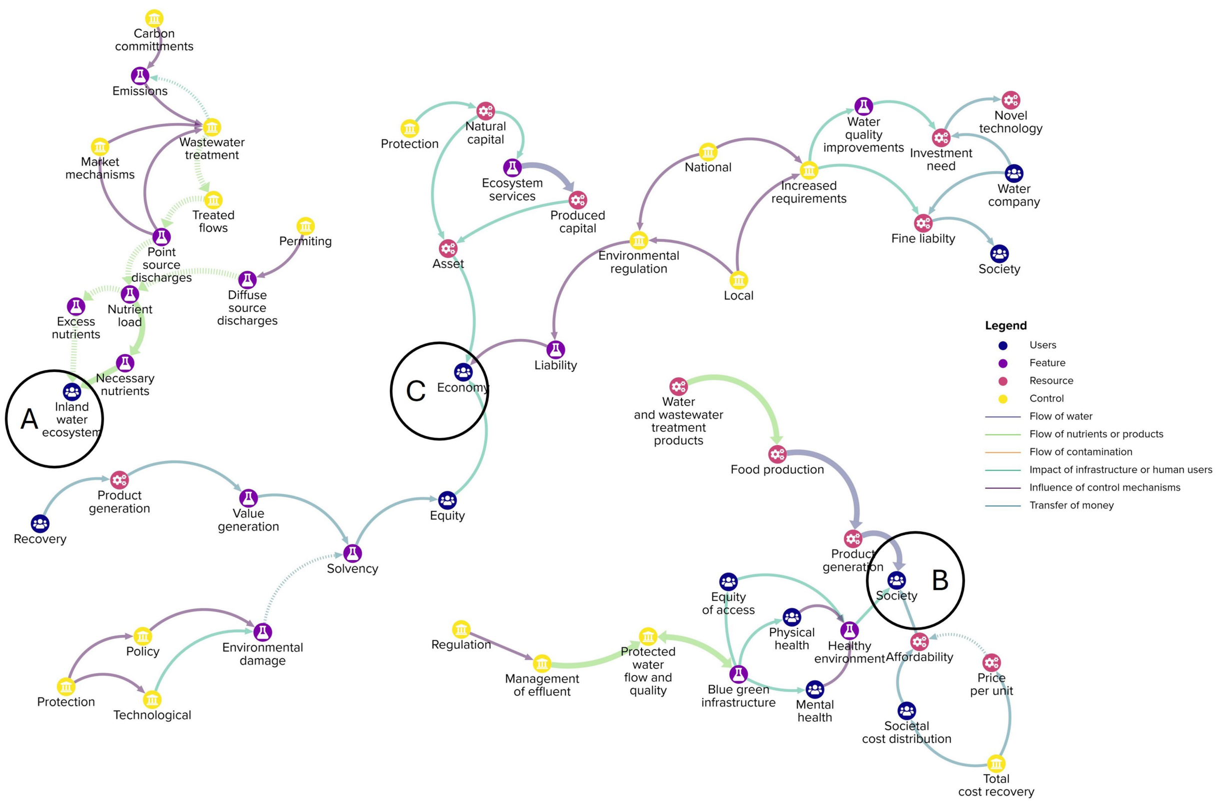

FIGURE 8
Visualization of specific impacts relating to nutrient recovery and recycling from three perspectives: environmental **(A)**, social **(B)**, economic **(C)**.

varying socio-economic contexts on the water system. A discussion of cultural evolution in this context underlines the interconnection between these activities and the complexity of initiating change within the water system. Strikingly, the analysis of impact chains from hard and soft governance through to impacts across social and environmental justice outcomes demonstrated common leverage points in product generation, treatment capacity and capability, urban development and cost recovery. Urban development was considered to encompass water resources, stormwater management, treatment capacity and treatment capability, thereby consolidating the leverage points into three key areas. These leverage points formed the basis of feedback loops in the development of a conceptual model that depicts the connection between governance, society and environmental outcomes. The interplay of relationships within these feedback loops can be further characterized within the tripartite links between value, social norms and technology. It is noted within these diagrams that the strength of feedback mechanisms may be impacted by delays in effects becoming apparent, leading to a cognitive disconnection between actions and impact; this is particularly the case where individual actions and behaviors are relied upon.

The conceptual model provides a depiction of relationships and system connections across multiple perspectives. This provides a notable output from the study, demonstrating the ability for this approach to draw together scientific and social phenomena within the system into a single, accessible conceptual model that is outcome-driven. Furthermore, incorporation of the complete cycle of water uses from consumption to generation of wastewater, and basing this within the natural water system in place of administrative boundaries has generated a systematic and holistic environmental justice-led approach. This contrasts with the '*people and resource*' focus which has frequently been applied. Incorporation of the variable impacts of considering water either as a public or economic good across the system adds to the discussion of these concepts. Especially considering that many of the mechanisms proposed to prioritize water consumption place it as an economic good, leading to commodification and subsequent unjust consequences. Reflecting water as both a pubic and economic good with social and environmental impacts, the conceptual model enables a combined approach that is rooted in a systems and justice framework.

System maps have been developed to be generically applicable across the surface water system in England; however, geographical specifics would need to be incorporated to enable application to a specific system, or catchment. To take account of differences in users of the water system and specific hydrological characteristics, a place-based approach is needed. To facilitate this localized development, participatory methods would be applied using systems maps as a common initiation point whilst ensuring that local context and priorities are incorporated. Additionally, these visualization tools would be of increased value in participatory decision-making if the conceptual model was supported by suitable metrics (an area of further work currently being undertaken by the authors). Further analysis of the system maps could also be undertaken to determine value calculations that could be used in financial mechanisms to enable justice-led management of the water system. The development of these system maps and conceptual model has been undertaken within the context of the surface water system within England. However the approach applied is applicable to multiple different contexts globally, and the issues of water and wastewater management and justice are present globally although with different manifestations.

Therefore, the visualizations and conceptual model that have been developed enable evidence-based societal and environmental impacts to be analyzed through an environmental justice lens. By creating visualizations that enable multiple perspectives to be incorporated within assessments of interventions, in this case described at the national scale, impacts across human and other-than human users can be investigated. In particular this supports the explicit consideration of outcomes from an environmental justice lens with specific elaboration on this concept within the surface water system. The outputs of this study create a novel platform to enable cross-sectoral and cross-societal exploration of drivers and impacts using a common method of communication.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the University of Birmingham Research Ethics Committee, Science, Technology, Engineering and Mathematics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

BMB: Conceptualization, Methodology, Visualization, Validation, Formal analysis, Writing – original draft, Writing – review & editing. DVLH: Supervision, Writing – review & editing. CDFR: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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