UNIVERSITY OF BIRMINGHAM

VISUALISATIONS TO SUPPORT ENVIRONMENTAL JUSTICE-LED DECISION MAKING IN THE UK WATER SECTOR

by

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ABSTRACT

Vital for a functional society and impacted by human activity, the management of water systems is essential. Within England, the water sector is in a state of flux responding to global events, socio-economic influences and regulatory changes. This is against a backdrop of increasing acknowledgement of inequitable impacts, particularly the cost of water services and river water quality across the population. Despite this recognition it is notable that within regulatory guidance the inclusion of justice themes is implicit rather than explicit. Engagement with industry experts throughout this study has highlighted an embedded short-term approach, particularly evident within wastewater management, and cross-sectoral discontent that this is the case. Consequently, there is a requirement, and practitioner appetite, to improve the consideration of future uncertainty within policy frameworks. Furthermore, there is recognition of the need to rebuild societal trust over the delivery of water as a public good. This study posits that new tools, namely visualisations and an indicator system, are needed. These aim to enable inclusive decision-making which incorporate systems approaches and an environmental justice framework.

This study applied a multi-stage method utilising systems approaches together with combined participatory and case study validation methods to generate visualisations and propose an environmental justice-led indicator system. The system boundary is defined as inland surface waters within England: the natural and human-influenced water system from headwaters to transitional areas including lakes and wetlands, constrained to England to ensure a consistent regulatory framework and organisational structures. Furthermore, applying a water system boundary, as opposed to administrative boundaries, fixed tools within a place-based

approach. System mapping explored relationships from perspectives of the environment, society and economy through a lens of environmental justice. This was enhanced through application of future scenarios to enable the consideration of alternative socio-economic contexts. Analysis revealed common leverage areas and enabled analysis of the impacts of policy, attitudes and behaviours. Further to this an indicator system has been developed to enhance these systemic approaches and create a common framework for analysis. This indicator system is derived from an environmental justice-led approach facilitated by analysis of system maps developed herein. This provides the ability to assess a system, and interventions within the system, including an evaluation of the impacts of potential future socio-economic contexts on these indicators. The outputs of the study were explored within different tiers of practice; at the organisational level applying water pricing measures, and at the intervention level through the implementation of a technological innovation.

The tools developed through this study create a framework for the translation of data into accessible information and knowledge through an environmental justice-led approach. Whilst it has not been possible to directly assess the impact these have on societal agency, the impacts of single-issue interactive maps on public engagement with the water sector in the last few years suggest this is a possibility. Combined with cross-sector interest in incorporating environmental justice-based indicators and visualisations developed herein provides confidence that these tools would support increased societal engagement, leading to greater societal agency over outcomes within the water environment. Moreover, basing these tools in environmental justice and utilising multiple socio-economic contexts into their development and analysis enables the inclusion of system-wide future uncertainty.

DEDICATION

'Tis rushing now adown the spout

And gushing out below,

Half frantic in its joyousness,

And wild in eager flow.

The earth is dried and parched with heat,

And it hath long'd to be

Released from out the selfish cloud,

To cool the thirsty tree

Elizabeth Oakes Smith,
"Water", stanza 2, in ''The Poetical Writings of Elizabeth Oakes Smith
(New York: J. S. Redfield, 1845), p. 136

I dedicate this thesis to my family – Ros, Saul, Elvie and Caelan –

for your patience and love to help me follow my passion.

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KEY TERMS

Bioresources	(also biosolids or sludge) Solid material generated through wastewater treatment. Commonly treated through anaerobic digestion to stabilise the nutrient rich material for reuse in agriculture and generate biogas which is converted into heat and power.
Catchment	An area of land, the water that collects within this area and moves through it.
eDNA	Environmental DNA. The use of bacterial DNA profiling to determine the source and pathway of pathogens within the surface water environment.
Environmental justice	Grassroots movement to address the cross-over between social justice and environmental degradation. Specific definition used herein: *"equity in the distribution of environmental benefits and harms for human and other-than human beings"* (Simpson et al., 2023).
Externalities	Events outside the direct system, and outside control of that system, that have an impact within the system.
Feedback loop	Occurs when a change in something ultimately causes a further change in the same thing. This can further the effect (reinforcing) or limit it (balancing).
Future scenarios	Extreme yet plausible socio-economic constructs that illustrate an extreme range of contexts within which the system may operate.
Inland surface water	Water environment from headwaters to transitional areas including streams, rivers and lakes.
Interdependencies	Relationships that effect and are affected by each other.
Intervention	An action, or series of actions, to elicit a change within the system.
Landscape	Geographic area incorporating land and water systems.
Leverage point	A place in a systems structure where a solution element, or intervention can be applied
Ofwat	Water Services Regulation Authority. Non-ministerial government department responsible for economic regulation of the privatised water and sewerage industry in England and Wales.
Operational catchment	Environment Agency term for a collection of waterbodies that form a discrete section of a surface water system.

Potable water	(also drinking water) 'Wholesome' drinking water that is supplied to individuals and businesses within quality parameters that are defined in law.
Reliable	Performance in design conditions.
Resilient	Continuation of functionality in the face of change (Rogers, 2018).
Sewage	(also wastewater) Wastewater that is sourced from homes and businesses. Within combined systems this is combined with rainwater.
Sewerage	Network for the collection of wastewater and transfer to a treatment facility. Conveys a combination of foul sewage and rainwater in combined systems.
Sustainability	A lifetime assessment based on environmental, societal and economic pillars.
Triple bottom line	Inclusion of environmental, social and economic value in business case and business model development.
Value	The importance or worth of something for someone or something.
Virtual water	Water embedded into goods which are traded.
Waterbody	A clearly distinguishable part of surface water.
Wastewater	Water that has been used and had its characteristics changed as a result. Sourced from homes and businesses.

ABBREVIATIONS

AMP	Asset Management Period
CAS	Complex adaptive system
CCW	Consumer Council for Water
CFU	Colony forming units
CLD	Causal loop diagram
CSO	Combined Sewer Overflow
DPSI	Drivers-Pressures-Status-Impacts
DWI	Drinking Water Inspectorate
EA	Environment Agency
EU	European Union
FW	Fortress World (future scenario)
GDP	Gross Domestic Product
GHG	Greenhouse gas
GSG	Global Scenarios Group
INCA	Integrated Catchment Model
INN	Innovation (EA scenario)
LR	Local Resilience (EA scenario)
LSOA	Lower Super Output Area
MF	Market Forces (future scenario)
NGO	Non-governmental organisation
NSP	New Sustainability Paradigm (future scenario)
PESTLE	Policy-Economic-Society-Technology-Legal-Environmental
PR	Policy Reform (future scenario)
PR24	Price Review 2024
RAPID	Regulators’ Alliance for Progressing Infrastructure Development
REF	Reference (EA scenario)
SB	Sustainable Behaviour
SDG	Sustainable Development Goals
STEEP	Society-Technology-Environment-Economic-Policy

STEEPLE	Society-Technology-Environment-Economic-Policy-Legal-Ethics
STEEPO	Society-Technology-Environment-Economic-Policy-Organisation
SSP	Shared socio-economic pathways
SWMM	Stormwater Management Model
SWRM	Sustainable Water Resources Management
UD	Uncontrolled Demand (EA scenario)
UV-LED	Ultraviolet light emitting diodes
UNICEF	United Nations Children’s Fund
UWOT	Urban Water Optioneering Tool
UWWTD	Urban wastewater treatment directive
WEAP	Water Evaluation and Planning
WEF	Water-energy-food
WFD	Water Framework Directive
WINEP	Water Industry National Environment Programme

1 INTRODUCTION

This study aims to create tools to enable cross-sectoral and cross-societal communication regarding the water environment and its management; it posits that these mechanisms are not currently embedded and such tools would enable more effective investment decisions. This has led to the development of two published papers[1,2], two further papers which have been submitted[3,4] and further papers in the pipeline. This thesis contains these publications either in part or in whole.

This chapter provides the context of the historic development of water infrastructure (Section 1.1) and changing awareness of water and sanitation in public health (Section 1.2), followed by a discussion of the value water holds in society (Section 1.3). This builds a picture of the current status of water infrastructure; however, this is subject to changing conditions and behaviours (Section 1.4) which management and investment decisions must incorporate. This leads to (Section 1.5) a definition of the research hypothesis and objectives.

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[3] BOWMAN, B. M., HUNT, D. V. L. & ROGERS, C. D. F. 2024. Visualising the surface water system. An environmental justice-led approach. Frontiers in Water, 6.
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1.1 Development of water infrastructure

Water is an essential component for life across all of nature and has been recognised as a human right in the UN Sustainable Development Goals, SDG6 (United Nations, 2015). However, human activity, industry, agriculture and urbanisation all disrupt the natural water cycle, both through direct impacts (Bell et al., 2021, Naden et al., 2016) and through the consequences of climate change altering the frequency, severity and location of rainfall (IPCC, 2021). This is leading to a situation in which water 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., 2019b, 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). Throughout history urban development, technology adoption and attitudes have transformed and shifted across the globe.

The earliest civilisations in human history directed human waste and rainfall away from buildings and urban centres. Archaeological evidence in the Mesopotamian Empire (ca. 4000-2500BC), ancient Greece (ca. 3200 – 100BC), and ancient Egyptian settlements (ca. 2000-500BC) demonstrated how a view of uncleanliness combined with flooding concerns in areas of increasing urbanisation led to the development of sanitation and storm water systems. Across China complex sewage systems emerged as urban areas developed over the past 4000 years (De Feo et al., 2014, Angelakis, 2017), and in the late-Neolithic (ca. 3200BC) settlement

Skara Brae on Orkney, Scotland, rainwater management was integrated into building structures (De Feo et al., 2014).

In the development of Roman infrastructure, extensive sewerage systems were present, particularly in Rome in the form of the Cloaca Maxima, incorporating management practices to enable street cleaning and regular flushing of sewers. As the Roman Empire expanded across Europe the concept of sewerage systems also proliferated, leading to sewer development in a number of places including London and York (De Feo et al., 2014).

Over time civilisations have grown, fallen and been morphed by changing influences, and as this has occurred, the importance of sanitation systems has also changed. The increase in privacy associated with the growth of Christianity, and the abandonment of infrastructure systems in the Early Middle and Middle ages across much of Europe following the collapse of the Roman Empire and shift in focus from development to war (De Feo et al., 2014) have influenced large-scale changes. However, the need for urban water infrastructure is a common theme that frequently re-emerges even before the importance from a public health perspective was fully understood.

1.2 Water, sanitation and public health

As early as ca. 470BC the Alcmaeon of Croton became the first Greek doctor to proclaim a link between the quality of water and health of the population (De Feo et al., 2014). This was progressed in the third century BC into the Hippocratic treatise: *Airs, Waters and Places* that explicitly linked the effects of climate and environment on human health (Angelakis, 2017). In this treatise the importance, or value, of water in maintaining public health was recognised which led to the development of a well-organised sanitation and effluent management system.

Further study of disease outbreaks are connected with additional developments in sewerage and rainwater management (De Feo et al., 2014).

Public health as a driver for the development of sanitation systems in the United Kingdom emerged to some degree in the 13th and 14th centuries with the introduction of public health legislation concerning the management of sewerage (Stanwell-Smith, 2010). Wastewater management was widely ineffective due to underground infrastructure being largely abandoned after the collapse of the Roman Empire, a widespread decrease in urbanisation in intervening years and movement towards open sewer systems. In 1347, there was a proclamation to forbid the disposal of wastes into the River Thames and other watercourses (De Feo et al., 2014). While this acted as discouragement, it was not accompanied by widespread development of alternatives to circumvent the public health consequences of uncontrolled urban sewage disposal. Therefore, the ability to achieve effective management was hampered by infrastructure advancement, societal attitudes and weak governance to adopt the transformation.

In the following centuries pressures on wastewater infrastructure, already under strain, mounted. The 16th century creation of the water closet, followed by development of flushing toilets in the 18th century which became common in houses with running water. By the 1840s it was compulsory for every London house to be connected to the sewer system. This increase in volume of water to be managed, due to technological developments, had been compounded by population increases aided by migration and improvements to infant mortality (De Feo et al., 2014, Stanwell-Smith, 2010, Emsley et al., 2018).

A number of cholera outbreaks are documented to have occurred in London in the 19th Century (De Feo et al., 2014), identified in early epidemiological studies as being caused by faecal contamination of drinking water. Despite this evidence, it took the 'Great Stink' of 1858 caused by the effect of a heatwave on untreated sewage in London to spur the authorities into taking action. Implying that it was the immediacy of impacts to those with power that instigated action and that prior to this point decision-makers were distanced from the effects. The next few decades saw the development of the first sewerage system of modern London overseen by Sir Joseph William Bazalgette (De Feo et al., 2014). Alongside this, the treatment of drinking water became established; chlorination was a requirement from the early 20th century in the UK (Turneaure, 1901) and large-scale infrastructure projects were established to facilitate the conveyance of drinking water, for example the Thirlmere Aqueduct in North-West England; this would mitigate the impacts of drought and population growth which had led to a substantial number of deaths (Greenwood, 2018).

The link between public health, drinking water contamination and sanitation is now well established in the regulatory and scientific community. However, this does not always translate into individual behaviours. Musacchio et al. (2021) noted that private well owners did not proactively manage against health impacts posed by flood risk and the best predictor of behaviours was the perceived level of risk along with personal and social norms. Conversely, the cholera outbreak in Yemen (2016-2017) highlights how knowledge of public health implications has been used in military strategy. In this case the intentional destruction of infrastructure had a severe impact on public health (Blackburn et al., 2020).

1.3 Harnessing value

The potential to use effluent as a resource, rather than consider it a waste, was prevalent in a number of civilisations in history including ancient Athens (De Feo et al., 2014), in civilisations in the Amazon through the formation of Terra Preta do Indio from ca. 5000BC (De Gisi et al., 2014) and more locally within the tanning industry in England.

Despite this, sewerage developments in modern times have overlooked the inherent value potential in wastewater and have viewed it as a waste to be disposed of. As a result, initial sewerage systems were principally collection and conveyance systems to move sewage away from urban centres. The historic development of sewers within England exacerbates this through mixing wastewater and rainwater in a combined system, limiting opportunities to utilise rainwater separately. The start of the 20th Century saw the emergence of the first organised treatment systems in the form of primary treatment and trickling filters (Naden et al., 2016). The later development of the activated sludge process in Manchester (Ardern and Lockett, 1914, Naden et al., 2016) and its ongoing advancement has transformed the potential of wastewater treatment (De Feo et al., 2014). However, the impact of increasing population, urbanisation and behavioural change has also led to substantial increases in the amount of nutrients present in domestic wastewater (Naden et al., 2016).

The end of the 20th Century was marked by regulatory change within the UK to provide improvements to environmental standards: phasing out of the disposal of sewage sludge to sea; introduction of Sludge Use in Agriculture regulations; and improved effluent treatment standards (Public Health England and Wales and Public Health Scotland, 1989, Directive 91/271/EEC, 1991, Directive 2000/60/EC, 2000). Understanding the organic matter and nutrient gain from the use of treated sewage sludge in agriculture, combined with diminishing sources of rock phosphate (Cordell et al., 2009), led to acknowledgment of the value to be gained from the nutrients held within sewage sludge. The start of the 21st century has seen widespread discussion of the energy, nutrient and product value held within wastewater. Indeed, there has been a shift in academic literature focus from wastewater treatment to resource recovery; however, this potential remains largely untapped due to a combination of factors (Marcal et al., 2021). Additionally the largest resource held within wastewater is water, yet this potential is largely unrecognised particularly where scarcity is not a high profile concern (Duckett et al., 2024).

1.4 Service provision in a changing world

1.4.1 Organisational models

Just over a century has passed since treatment works for water and wastewater became commonplace, and in this time the structure of service provision has changed significantly with movement between local context-led organisation and national standardisation. Water and wastewater services are no longer provided through municipal suppliers of drinking water and wastewater collection; in 1974 the water industry in England and Wales was regionalised into ten Regional Water Authorities. Co-ordination of these authorities and management of national policies was undertaken by the newly formed National Water Council (Byatt, 2013). Pressures on public spending through the 1970s led to deterioration in river water quality which is observable in historic trends of organic carbon, nitrogen and phosphorus (Naden et al., 2016). Structural re-organisation of the delivery of water and wastewater services led to privatisation in 1989 with an objective to create a privatised industry that was regulated to promote efficiency, enhance competition and protect customers (Byatt, 2013). Since privatisation there has indeed been an improvement in river water quality (Naden et al., 2016), however this cannot be wholly attributed to the effect of privatisation as it has coincided with increasing requirements for treatment through European Union (EU) legislation which includes the Water Framework Directive (WFD) (Directive 2000/60/EC, 2000) and the Urban Wastewater Treatment Directive (UWWTD) (Directive 91/271/EEC, 1991). The combination of infrastructure development and application of policy has therefore 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.

The water industry in the UK is once again in a state of flux; the basis of environmental drivers that have led to river quality improvements has come through European Union (EU) legislation. However, without this independent steer of standards there is uncertainty over the future direction and timescale for environmental improvements. This is accompanied by a backdrop of increasing stimulation of both competition and collaboration from Ofwat. These behaviours are at odds with each other and incorporate the introduction of competitive markets for retail customers and bioresources (Ofwat, 2024a), whilst collaboration in innovation is encouraged through the Ofwat Innovation Fund (Ofwat, 2024c). There is also growing awareness of the environmental and social impact of the water industry alongside its role in public health (Bauwelinck et al., 2020, Bell et al., 2008, De Petris et al., 2021, Agyeman et al., 2016, Buck et al., 2021).

1.4.2 Operational context

Interventions, i.e. an action(s) to establish a change, are undertaken within the water industry to address regulatory requirements. This is a function of regulation of the industry and although reference may be made to alignment, or progress towards, long-term planning (UK Government, 2018, Ofwat, 2022), the priority is compliance with the regulation at the time it is enforced. Consequentially, focus is prioritised on near-term certainty of achieving regulatory targets with recognition of risk and certainty associated with changing conditions that can be predicted based on either known events (i.e. planning developments) or historic and projected trends (i.e. water consumption rate). However, there are circumstances outside of the control of the water sector that impact long-term operation of interventions; how these externalities are included in assessments and decision-making is becoming increasingly pertinent. Just as population and drought pressures led to infrastructure developments in the 19th century, there is renewed pressure on water sources linked to population increases, environmental water quality, droughts and the impacts of climate change (Greenwood, 2018).

1.4.2.1 Water quality drivers

Potable water within the UK is regulated by the Drinking Water Inspectorate (DWI) stipulating the provision of safe and wholesome water. This has led to the protection of raw water sources through catchment management (United Utilities, 2024) and land management practices in nitrate vulnerable zones (UK Government, 2024).

The wastewater sector is largely driven by regulatory requirements to improve river and coastal water quality and as such, any investigation into challenges and opportunities should sit within this context. Since the start of the 21st Century the WFD has been fundamental to determining advancements in treatment standards and effluent quality through the development of River Basin Management Plans. However, further improvements are needed (Marcal et al., 2021), including addressing emerging contaminants such as pharmaceuticals and microplastics (Brammer et al., 2018, Duis and Coors, 2016, Onoja et al., 2022). Numerical limits and specific permit conditions are driven by UK government implementation of EU directives, with geographical implementation set out within the Water Industry National Environment Programme (WINEP). The Environment Act (UK Government, 2021a) sets out the roles and responsibilities following the UK leaving the EU.

1.4.2.2 Net zero carbon commitment

There is global commitment to mitigate the impacts of human activity on the planet and meet the Principles of the Paris Agreement and UN Convention on Climate Change 1.5^{0}C pathway (United Nations, 2023b, United Nations, 2023a). As the fourth most energy intensive industry in the UK the water industry has set a target of net zero by 2030 (Water UK, 2020) and Water UK has signed up to UNFCCC's Race to Zero Campaign (Climate Champions, 2021). However there are rising concerns over whether this can be measured and calculated accurately (Black et al., 2023) and whether this is achievable (Black and Thompson, 2023). Nevertheless, stating a target and aim has focused attention within the industry to make progress in this direction.

Activity over the past decade has, rightly, focussed on reducing greenhouse gas (GHG) emissions associated with energy consumption. However, the impact of water and wastewater services includes fugitive emissions from treatment processes. Ultimately it will also include emissions associated with the supply chain, although the inclusion of these emissions will come into effect after 2030 (Water UK, 2020). The quantification of GHG emissions from treatment processes is the subject of a growing body of research (Aboobakar, 2014, Ahn et al., 2010, Brotto, 2016, Roy et al., 2021, Valkova et al., 2021, van Dijk et al., 2021) which highlight the range of emission factors that have been observed. Emissions can be impacted by a range of factors including the treatment technology, operating conditions and treatment objectives.

1.4.2.3 Climate change

Climate change has impacts on the provision of water and sanitation services due to its impact on weather patterns both in terms of stormwater management (Zheng et al., 2021) and subsequent impacts on Combined Sewer Overflow (CSO) operation, discharge permits and the availability and quality of raw water for potable water supply (Musacchio et al., 2021). There are potential opportunities to use alternative and novel methods or technologies to mitigate these impacts and provide a more resilient service to the community. However, adoption of novel technologies is restrained in an industry that is risk averse (Ofwat, 2024c) and social acceptability of alternative water sources is low (Duckett et al., 2024). The confluence of increasing urbanisation with the impacts of climate change are once again exerting stresses on existing water and wastewater infrastructure, as well as water quality within the catchment (Strokal and Kroeze, 2020).

1.4.2.4 Demographics

Population changes, behaviours and attitudes impact expectations and requirements of water and sanitation services. The trend of decreasing per capita consumption of water was reversed during 2020/2021 at the time of restrictions due to the covid-19 pandemic (Department for Food & Rural Affairs, 2024); as this is reported as a 3-year moving average, how this has changed consumption over the long-term is not yet apparent. Indeed, the establishment of

Industry 4.0, combined with the Covid-19 pandemic accelerating the rate of technology adoption, has the potential to create long-term change in the way in which society is structured, impacting behavioural norms and the rate of urbanisation (Calza et al., 2020).

The trend of increasing urbanisation over the past few hundred years has led to fundamental changes in the ways the population interacts with the environment and how waste is managed (De Feo et al., 2014). The adoption of new technologies such as detergents, and their subsequent regulation in order to mitigate the impact of use on wastewater characteristics (Naden et al., 2016) impacted the nutrient load flux to watercourses both in terms of total mass and spatial distribution within the past century. This demonstrates how a relatively small change can have far-reaching consequences. Extrapolated over multiple behaviour and product characteristics including, but not limited to, water consumption, pharmaceutical use and surface water management, could substantially change the requirements for water and sanitation services into the future.

1.4.2.5 Circular economy

The predominance of the linear economy, including in the provision of water and sanitation services, in society is evident, not least in the reluctance to adopt water reuse (Duckett et al., 2024). Nevertheless, there is growing interest in the concept of the circular economy (Jupp et al., 2021, Marcal et al., 2021, Masi et al., 2018, Sauvé et al., 2021). The implementation and adoption of this approach, however, is dependent on the formation of relevant markets for products and public acceptance. Therefore, the socio-economic systems which are in place have a substantial influence on movement from theoretical resource recovery to an actualisable circular economy.

Discussion of the circular economy has broadly focused on resource use, however there are broader connotations. If the concept of the circular economy is applied widely it could re-shape how the economy is structured. Those who advocate this (Swedish Sustainable Economy Foundation, Undated (accessed 2021), Raworth, 2022) have argued that it could lead to a more equitable society where value is retained in the system and prices of goods, such as water, reflect their value to society as a whole, including their environmental, societal, amenity and health value.

1.4.2.6 Innovation

There is a wealth of research being undertaken into advancements in treatment technologies (Coward et al., 2018), resource recovery (Kehrein et al., 2020) and intensification of nature-based solutions (Gupta et al., 2021), as well as advancements within the network such as the deployment of sensors and autonomous robots such as Pipebots (https://pipebots.ac.uk/). However, this activity is frequently focussed on low technology readiness levels (TRLs) with limited investment into progressing these to higher TRLs at which stage they would be suitable for trial and implementation (Coward et al., 2018).

Some technologies are breaking through from research into industry applications, although with a considerable time lag; ultraviolet light emitting diodes (UV-LEDs) were first mentioned in the literature in 2010 (Coward et al., 2018) with commitment to full-scale application not appearing until 2018 (Water and wastewater treatment online (WWT), 2018). To assist the progression of technologies to implementation water companies have developed innovation platforms to bridge this gap. The Ofwat Innovation Fund aims to stimulate collaborative innovation across the industry and the UK 2050 water innovation strategy sets out common themes (United Kingdom Water Industry Alliance, 2020). Despite this, taking the step to implement new technologies, especially if these are at low TRLs, is considered high risk. There is potential that managing this risk in a different way will open opportunities for greater innovation that could lead to transformative change in the water industry.

1.4.2.7 Equity of impacts across society

Whilst the standard of potable water supply is equivalent across the UK, wastewater impacts are more inconsistent and the cost of providing water services is variable. Some of these impacts are related to the variables described previously, however others are more systemically entrenched into organisational structures.

Differences in weather patterns exist between regions in England, and the impacts of climate change (Botturi et al., 2020, Rizzo et al., 2020) exacerbate these differences. The abundance of legacy combined sewers and urbanisation increasing impermeable surfaces (Medupin et al., 2020) all impact the probability of CSO spills and contribute to geographic variation. Additionally, the condition and characteristics of the receiving water (i.e. the river) will impact the effect of treated or untreated sewage effluent which is discharged. For example, a large, frequent spill into a small chalk stream will have greater impacts than a small, infrequent spill into a large, fast-flowing river. This creates both water environment spatial inequity as well as cost inequity as the investment required to address this issue is not evenly distributed across the country (Water UK, 2024b).

Consumer Council for Water (CCW) investigations have indicated that 10% of households regularly struggle to pay bills (Consumer Council for Water, 2021a). Additionally, there is regional variation in that average bills (within England) vary between £363/year to £466/year

(Water UK, 2024a) with increases requested for the next investment period (Ofwat, 2024d). The default position of charges linked to rateable value of the property is considered regressive, this is exacerbated by adoption of water metering being biased towards more 'active' groups which are also typically more affluent. Furthermore, non-universal metering has the consequence of cost-savings by metered customers leading to increased prices for unmetered customers (Bayliss, 2014).

1.4.3 Incorporating uncertainty into decision-making

These factors, and others, combine to create uncertainty over the future conditions under which infrastructure investment must operate. This extends not only through explicit design parameters, but also into societal priorities, behaviours and values. These effects, and their specific and combined impacts, are not straightforward to identify due to the nature of the water environment as a complex adaptive system (CAS) or systems with emergent and non-linear properties. Methods to assess such systems would be of value to enable a systemic approach and enable cross-sectoral cooperation and communication.

The rise in awareness of increasing urbanisation and climate change impacting the future sustainability of developments has been a driver for a range of research enquiries into increased sustainability in urban development. For example, assessment of developments within urban centres and how these can be aligned to achieving the long-term aspirations of the cities and their citizens (Leach et al., 2020). Additionally, the Urban Futures and Liveable Cities methods (Rogers et al., 2012, Rogers and Hunt, 2019) create frameworks which allow aspirations for an urban area to be documented and the impacts of potential developments assessed against these aspirations, both in the current context and in a range of potential future scenarios. The success of methods such as these lies in utilising a wide lens through which a change is assessed both now and into the future. In this way, the assessment reflects the wider environment that the change sits within, the interactions it has with the complete system and the benefits against a wide range of criteria. In the case of the UK water industry, a broad focus such as this could enable an inclusive assessment of the system and how this integrates with society. This has formed the basis for the following research objectives.

1.5 Aims and objectives

The appetite for long-term management within the water sector is reflected in the development of 25-year environment plans (UK Government, 2018) and calls for a review of the sector (Department for Environment Food & Rural Affairs, 2024). This recognition of the problem being faced also reflects that current frameworks and assessment mechanisms are not sufficient to address current or future requirements. This research will endeavour to further understanding through the development of tools to enable effective long-term management of the water environment. In doing so this study aims to address the following hypotheses:

Visualisation tools are an effective means to present information and knowledge enabling consideration of future conditions, inclusive decision making and societal agency in the management of the water environment.

This hypothesis will be investigated through the following six objectives which aim to develop and evaluate the use of tools to enable the inclusive representation of knowledge.

O1 – Explore relationships across the surface water system

This objective will focus on providing an understanding of the pressures faced by a surface water system and the direct and indirect consequences of actions. This will require the boundary of the system to be defined along with the goal. The output should be accessible across disciplines and sectors in order to enable inclusive discussions. Sections 2.1 and 2.4 of the literature review provide an analysis of existing uses of methods to explore relationships within a system. The method applied is presented in Section 3.2 and the results are provided in Section 4.1.

O2 – Explore these relationships using future scenarios

The potential for external impacts to vary these relationships should be understood to facilitate decision-making and the implementation of interventions that enable achievement of objectives over the long-term. An understanding of an appropriate level of longevity is required as well as the method through which future uncertainty will be incorporated into assessments. Section 2.1 of the literature review discusses the range of options available to consider future operating conditions, whilst Section 2.5 delves further into the use of future scenarios. Section 3.3 describes the method which has been applied and the results are provided in Section 4.2.

O3 – Define key points of interaction across perspectives and future scenarios

Understanding relationships enables visualisation with a high degree of detail; however, further analysis is required to enable key interactions and leverage points to be understood, as well as enable discussion at a more strategic level. Section 3.4 describes the method which has been applied to analyse and simplify visualisations of key interactions and the results are provided in Section 4.3.

O4 – Refine the exploration of key points of interaction within perspective-driven system maps and across future scenarios into a causal loop diagram of the surface water system centred on the key points of interaction

A conceptual model of the relationships, in the form of a causal loop diagram (CLD), has been developed and examined to further the depth of understanding. A specific form of systematic assessment, CLDs are a method of qualitatively visualising causal connections and feedback loops (Guest et al., 2010) to highlight influencing relationships within a system (Barbrook-Johnson and Penn, 2022). Section 3.5 describes the method applied to develop the CLD which is subsequently presented in Section 4.3.

O5 – Define indicators to represent holistic concerns across the surface water system and reflect the key points of interaction

An indicator is a critical underpinning of an indicator system along with metrics and benchmarks, this combination provides an assessment of current status, which in turn enables assessment of the direction of travel as well as the relative position in relation to the target (Hunt et al., 2008). There is the additional ability to provide comparative assessments across geographical areas, thus enabling investment decisions to be grounded in common criteria. Section 3.6 provides a description of the methods used to review existing indicators and propose indicators based on the findings from O3 and O4, including validation of the approach. The outputs are provided in Section 4.4 which also includes example implementation of the proposed indicators.

O6 – Application at different tiers of practice

The outputs of O1-O5 as tools to enable visualisation and assessment at the system scale are combined and applied to the inter-related topics of social norms, value and technology associated with two example interventions. The first of these are governance mechanisms for water pricing, and the second is a technological innovation. Section 3.7 describes the method which has been applied for these assessments and a discussion of the findings is provided in Sections 5.3 and 5.4.

2 CRITICAL REVIEW OF THE LITERATURE

A combination of academic and grey literature has been reviewed to characterise the literature landscape within which the subsequent research sits. This has been reviewed in two ways, through completion of a systematic review and continuous appraisal of existing and emerging research related to key topics of interest.

The systematic review (Section 2.1) provides an analysis of the literature using defined search criteria, completed at the start of the research period and published in early 2022. Footnotes have been added to provide updated analysis where additional guidance documents have been published since this time. The systematic review has provided justification for the direction of the research through identification of the growing body of knowledge associated with decision-making assessments. Identified methods include both participatory and model-based approaches with the choice of method dependent on the specific context and goals of the application. Within these assessments the inclusion of sustainability and justice considerations has been at global or national scales rather than considering an individual system. The systematic literature review identified a need to transparently represent relationships within a system both to engage a variety of actors with active discussion and allow its interrogation. In this latter role, accessible visualisations form a pivotal role in the ability to collaboratively develop and challenge boundaries, interdependencies and interactions so that the assessment is relevant and transparent. The systematic review has set the direction of the research to develop an environmental justice-led approach to visualising system interactions, both now and in alternative futures, as well as identifying indicators to support assessments.

The remainder of this chapter (Sections 2.2-2.6) provides an appraisal of current and emerging research trends focusing on the key topics of environmental justice (Section 2.2), the value ascribed to water (Section 2.3), system mapping to generate visualisations of relationships (Section 2.4), the application of future scenarios (Section 2.5), and finally, the use of indicators in assessments of water systems (Section 2.6). This ongoing review of key topics within the literature has guided the development of research approaches and objectives to align with and include recent developments. Section 2.7 provides an overview of how this literature landscape has been used to develop new visualisation and assessment tools.

2.1 Systematic review. Gazing into the crystal ball: A review of futures analysis to promote environmental justice in the UK water industry[5]

2.1.1 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 upgrade to maintain or improve treatment processes which

[5] This section is a replication of a published article (BOWMAN, B. M., HUNT, D. V. L. & ROGERS, C. D. F. 2022. Gazing into the Crystal Ball: A Review of Futures Analysis to Promote Environmental Justice in the UK Water Industry. Sustainability, 14.) with additional footnotes to update the discussion in line with more recent publications and guidance documents.

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 (Rogers and Hunt, 2019, Rogers et al., 2012). 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 (UKWRIP Water and Cities Action Group, 2015).

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.

2.1.2 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*' (United Nations Report of the World Commission on Environment and Development, 1987). The application of this definition is then further conceptualised as consisting of three pillars—social, economic and environmental (Purvis et al., 2018)—as depicted in the visualisation in Figure 2-1[6].

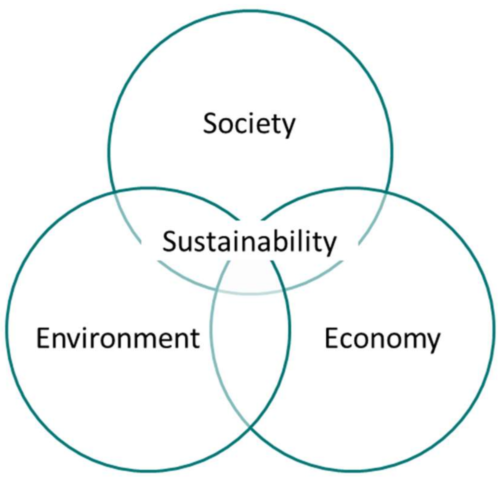


Figure 2-1: Visualisation of sustainability. Reprinted from Purvis et al. (2018)

In the global context, discussion of sustainability has led to the 2015 adoption of the United Nations Sustainable Development Goals (United Nations, 2015). Since this agreement, global pressures have escalated around two themes: climate and environmental change; and

[6] There is some dispute over the most appropriate representation of sustainability with alternatives including a nested view of the economy within society, all of which exists with the environment. Indeed, this nested view is the framing that is recommended later in this study (Section 4.1).

increasing inequality, both within and between nations (United Nations Environment Programme, 2021), 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 (Sadr et al., 2020, La Rosa and Pappalardo, 2020, Goytia et al., 2016, Lawson et al., 2020). Indeed, Sadr (Sadr et al., 2020) 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 (Neal et al., 2014, Shrimpton et al., 2021), 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 study, due to the mature status of the UK water industry in the provision of public health needs, environmental justice is proffered as the goal[7]. 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 (Adams et al., 2020, Romero Lankao, 2011, Agovino et al., 2020, Greiling and Grub, 2015, Liao et al., 2019, Homsy and Warner, 2020, Hanna and

[7] The definition of environmental justice and its relevance within the context of the UK water sector is expanded on in Section 2.2.

McDonald, 2021). 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 (Byatt, 2013, Bayliss, 2014). The situation differs across the devolved nations of the UK, so this study 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 2-2). Ofwat, through the Price Review process, is regarded as the means by which Defra is able to influence the direction of the water industry (Department for Food & Rural Affairs, 2021, Department for Food & Rural Affairs, 2022).

The Water Act 2014 gave Ofwat, and thereby the UK water industry, an additional remit of long-term resilience of water and wastewater services (Ofwat, 2017). Since then, a number of published government documents have incorporated resilience (Figure 2-3), which is typically thought of in infrastructure as the ability of a system to efficiently resist, adapt and recover from shocks (National Infrastructure Commission, 2018). Ofwat considers resilience in terms of financial, corporate and operational resilience to ensure that water and wastewater services are provided regardless of external disruption (Ofwat, 2017).

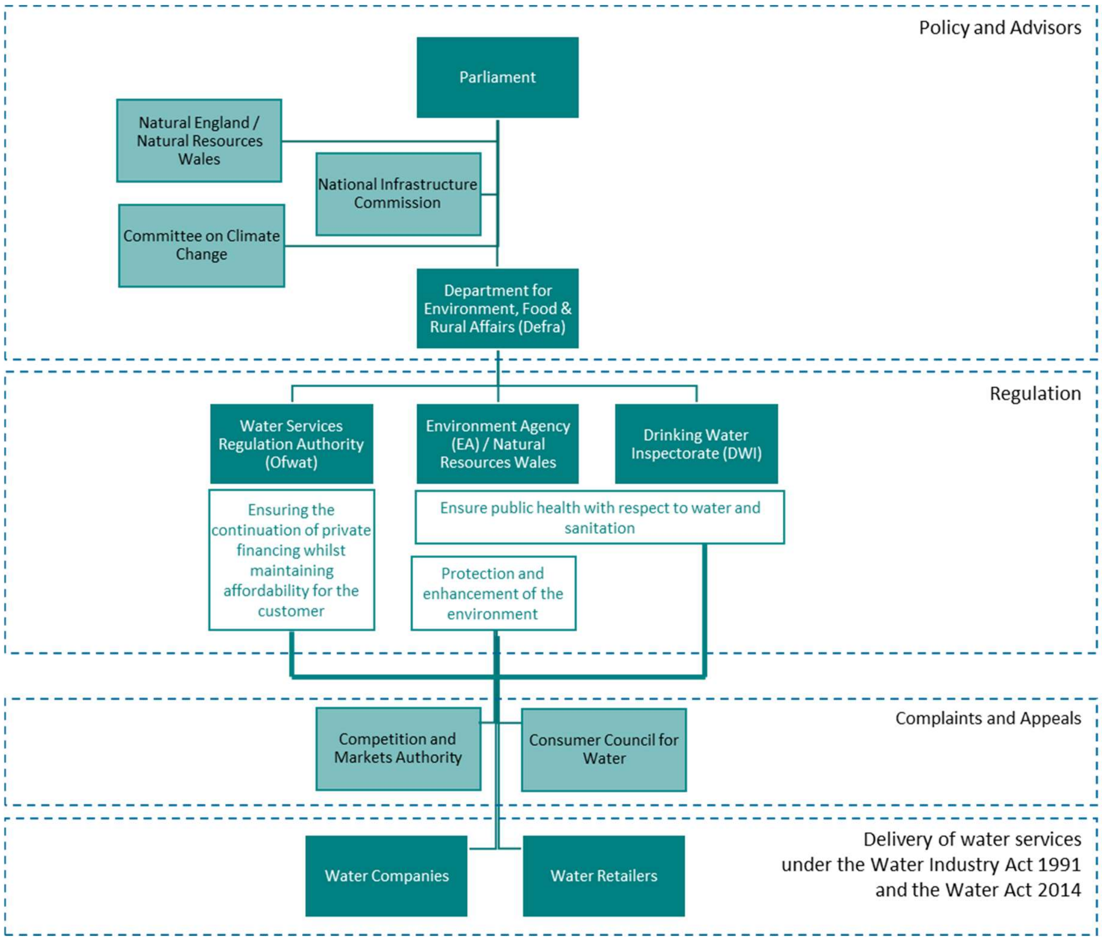


Figure 2-2: Regulatory structure of the Water Industry in England. In Wales Natural Resources Wales operated in the equivalent role to the Environment Agency.

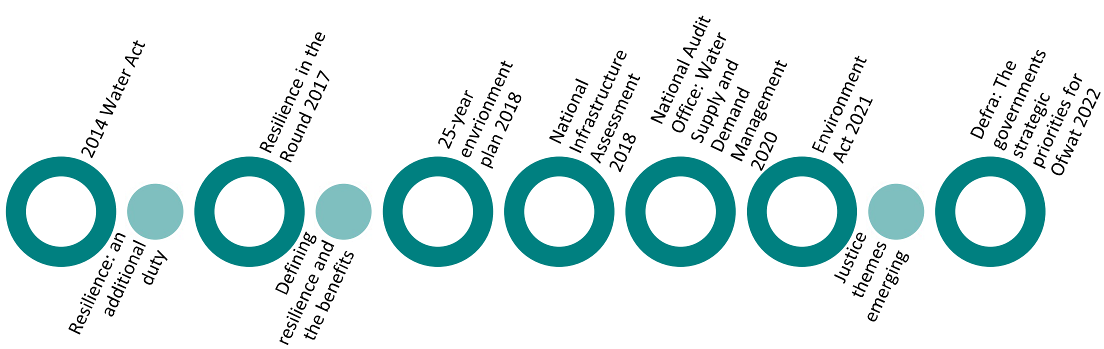


Figure 2-3: Governmental water industry publications highlighting the references to resilience and environmental justice

The 25-Year Environment Plan (UK Government, 2018) 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 (Department for Food & Rural Affairs, 2021, Department for Food & Rural Affairs, 2022). 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 (Ofwat, 2020). 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.

The guidance in Price Review 2024 (PR24) is yet to be fully published, although consultation documents imply that adaptive planning may be featured (National Audit Office, 2020, Ofwat, 2021)[8]. 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’

[8] The final methodology for PR24 does indeed contain reference of the need for long-term planning, with a 25-year delivery strategy setting the context for the 5-year business plan, and explicit requirement to incorporate adaptive planning (OFWAT 2022. Creating tomorrow, together Delivering UK government priorities for the English water sector through our 2024 price review final methodology. *In:* OFWAT (ed.). Birmingham, UK: Open Government Licence.).

states, which are used to stress test water company strategies (Ofwat, 2021). 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[9].

2.1.3 Method

A research hypothesis[10] 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, YET THEIR USE IS NOT EFFECTIVELY EMBEDDED WITHIN UK WATER GOVERNANCE.

The review will incorporate analysis of the literature in terms of 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 2-4) 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

[9] The impacts of this will become apparent as the water industry moves into Asset Management Period 8 (AMP8).
[10] This is the hypothesis for the systematic literature review which was used to refine the research hypothesis for the complete study.

followed PRISMA guidelines as far as feasible (Moher et al., 2009); the steps undertaken, search terms, and results are presented here.

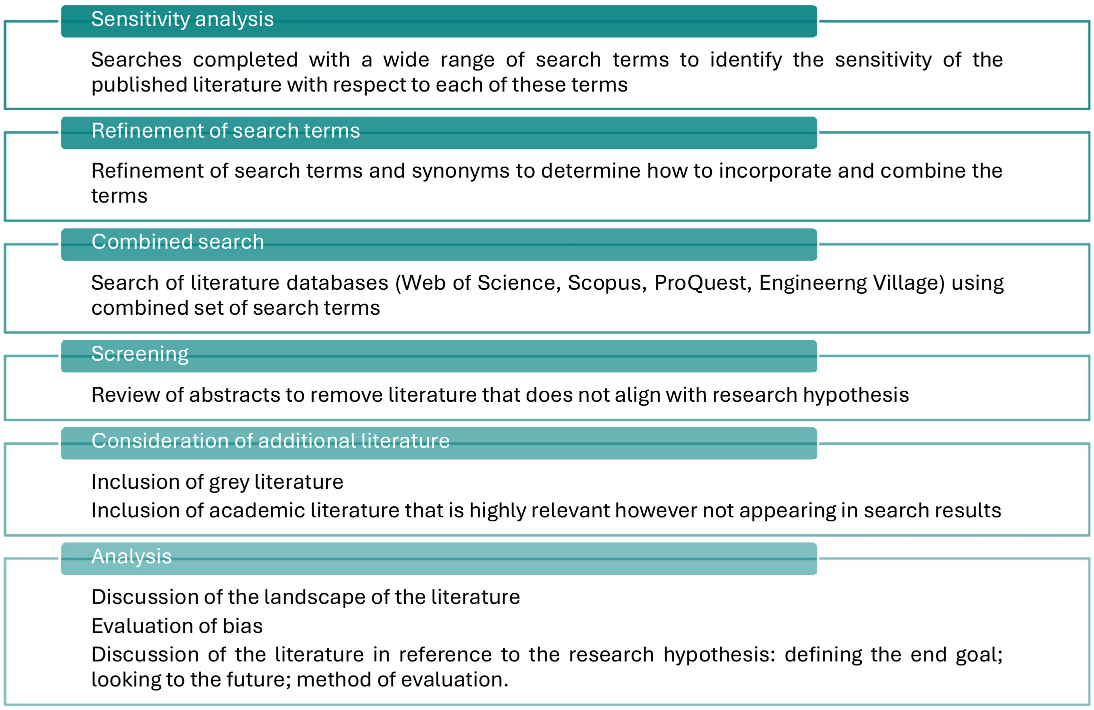


Figure 2-4: Systematic literature review method.

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 2-1). Searches were not time-limited[11], and search results from the Web of Science, Scopus, ProQuest, and Engineering Village databases (Table 2-2) were combined to generate a list of 70 individual records.

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

[11] The searches were conducted in April 2021.

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.

Table 2-1: Systematic 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

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.

*Table 2-2: Number of search results from range of databases. *indicates that 'risk' and 'uncertain*' were removed from the combined search due to unmanageable number of returns when including these terms.*

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*

This process resulted in a total of 31 publications for full analysis and discussion (Table 2-3 and Table 2-4). 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.

2.1.4 Results

From the process described in Section 2.1.3, 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 2-5).

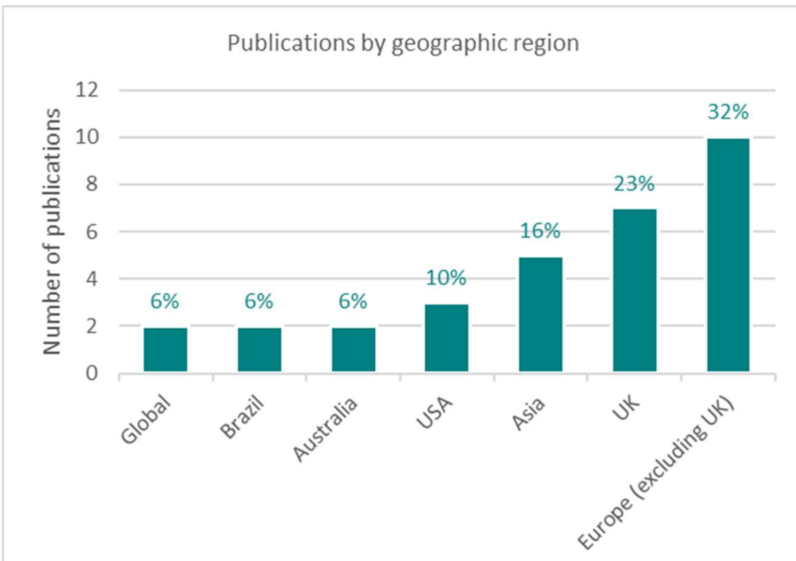


Figure 2-5: Literature search results grouped by geographic region.

When grouped by the focus of the study (Table 2-3), 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 2-4.

Table 2-3: 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. (2019); La Rosa and Pappalardo (2020); Nikolopoulos et al. (2019); Sadr et al. (2020); Sitzenfrei et al. (2010); Sitzenfrei et al. (2014); Song et al. (2018)
B - Water resources management	Management of water resources for potable water provision	6	Ahmadi et al. (2020); Gurluk and Ward (2009); Kumar et al. (2016); Piniewski et al. (2014); Tomlinson et al. (2020); Wada et al. (2017)
C - Flood mitigation	Assessment of flood mitigation	4	Borris et al. (2016); de Brito et al. (2018); Goytia et al. (2016); Franco et al. (2018)
D - Water quality (river)	Assessment related to river water quality	2	Crossman et al. (2013); Sultana et al. (2019)
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. (2019); Calvin et al. (2019); Heller et al. (2014); Howarth and Monasterolo (2017); Lawson et al. (2020); Li et al. (2019b); Markolf et al. (2018); Nguyen-Viet et al. (2009); Pedde et al. (2021); Qiu et al. (2018); Xu et al. (2015); Yu and Lu (2018)

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.

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

Table 2-4: Literature search results, not including grey literature.

Record	Year	Location	Focus of study	Method of analysis	Timeframe or Horizon	End goal
Ahmadi et al. (2020)	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. (2019)*	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. (2016)	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. (2019)*	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. (2019)	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. (2013)	2013	UK	Water quality	INCA-P - Integrated Catchment model of phosphorus dynamics	To 2060	Adherence to regulatory output
de Brito et al. (2018)	2018	Germany	Flood mitigation	Multi-criteria approach for participatory flood vulnerability assessment	N/A	Individual and group flood vulnerability maps
Goytia et al. (2016)	2016	England, France, Sweden, The Netherlands	Flood mitigation	N/A – assessment of regulatory frameworks across selected countries	N/A	Adaptation in national water laws
Gurluk and Ward (2009)	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. (2014)	2014	Brazil	Generalised	Participatory method	20-year horizon	Generation of strategic sanitation plan

Howarth and Monasterolo (2017)	2017	UK	Generalised	Participatory / co-production method	N/A	Understanding energy-food-water nexus shocks
Kumar et al. (2016)	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 (2020)	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. (2020)	2020	UK	Generalised	N/A	N/A	Resilience in the water sector
Li et al. (2019b)	2019	China	Generalised	Input-output models linked with system dynamics models	2025	Cleaner production strategies
Markolf et al. (2018)	2018	USA	Generalised	N/A	N/A	Resilience across aspects of a system to prevent lock-in
Nguyen-Viet et al. (2009)	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. (2019)*	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. (2021)	2021	UK	Generalised	UK specific shared socioeconomic pathways	2100	Development of narrative future scenarios
Piniewski et al. (2014)	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. (2018)	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. (2020)	2020	UK	Urban systems	Adaptation pathways	2015-2050	Decision-making with reliability, resilience and sustainability
Sitzenfrei et al. (2014)	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. (2010)	2010	Austria	Urban systems	DynaVIBe - Dynamic Virtual Infrastructure Benchmarking	N/A	Generation of virtual case studies to feed into modelling systems
Song et al. (2018)	2018	China	Urban systems	Quantitative-Dynamic linear input-output model	12-year horizon	Sustainable economic development
Sultana et al. (2019)	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. (2020)*	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. (2018)	2018	Brazil	Flood mitigation	Social Vulnerability Index	N/A	Classification of social vulnerability with respect to floods
Wada et al. (2017)	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. (2015)	2015	Australia	System goals	N/A	N/A	Resilience as a framework for sustainability
Yu and Lu (2018)	2018	China	Integrated systems	EKC – Environmental Kuznets Curve	N/A	Balance of economic growth and water quality in transboundary river systems

Ahmadi et al. (2020) and Kumar et al. (2016). In a complex system, such as water catchments and groundwater, a systems approach has been noted as important for the consideration of justice (Neal et al., 2016).

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 Acosta et al. (2020), Calvin et al. (2019), Jung et al. (2021), Kebede et al. (2021), and others. That this is not reflected at a regional or catchment scale, or within the water context, has proved to be an unanticipated finding from the review.

2.1.5 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 2.1.5.1), considering the future (Section 2.1.5.2) and methods of evaluation (Section 2.1.5.3).

2.1.5.1 Defining the End Goal: Resilience, Sustainability and Environmental Justice

2.1.5.1.1 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. (2015) 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 (Rogers, 2018) and through current, human, terms (Xu et al., 2015). 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. (2020) 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 (Goytia et al., 2016) 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. (2020) 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 2-6). 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 (La Rosa and Pappalardo, 2020). Dasgupta (2021) 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.

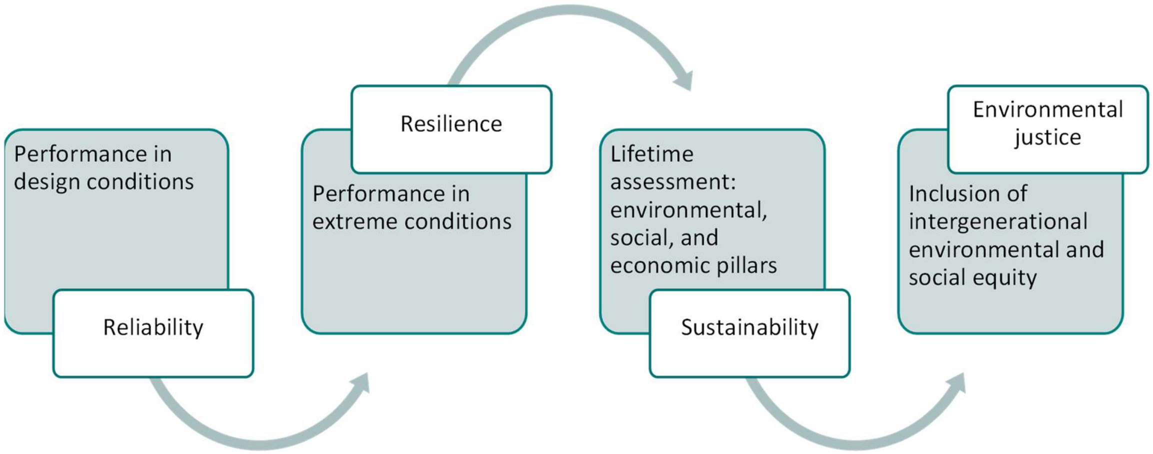


Figure 2-6: Hierarchy of goals in assessment methods, adapted from Sadr et al. (2020) and La Rosa and Pappalardo (2020)

Economic drivers are present in the assessments of Song et al. (2018), Li et al. (2019b), Gurluk and Ward (2009) and Tomlinson et al. (2020) 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 (UK Government, 2018). 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 (Dasgupta, 2021, Proctor et al., 2021). As sustainability is typically defined in terms of the combination of the three pillars of economy, environment and society (Purvis et al., 2018), 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 (Bayliss, 2014, Byatt, 2013, Ofwat, 2017). Each of these has critical implications for the methods adopted and the process by which conclusions can be drawn from analyses undertaken therein.

2.1.5.1.2 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. (2013) and Ahmadi et al. (2020) and short-term assessments undertaken in Song et al. (2018) and Li et al. (2019b).

The implications of technological interventions, when considered in isolation, particularly regarding lock-in and adaptive governance, are discussed in detail by Goytia et al. (2016), Markolf et al. (2018), Lawson et al. (2020) and Sadr et al. (2020). 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. (2018) 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. (2018) 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.

2.1.5.1.3 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 (Blair et al., 2019). 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 (Rogers et al., 2012, Environment Agency, 2017b) 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 (2009) 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.

2.1.5.2 Looking to the Future

2.1.5.2.1 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 2-5) are specific to the focus of the investigation and can be seen to vary between 5 (insufficient for intergenerational considerations) and 35+ years.

Table 2-5: Timeframe for assessment (note: not all of the reviewed literature included assessments into the future)

Timeframe	Nr	References
5-12 years	2	Li et al. (2019b), Song et al. (2018)
20-25 years	6	Ahmadi et al. (2020), Gurluk and Ward (2009), Heller et al. (2014), Nikolopoulos et al. (2019), Sitzenfrei et al. (2014), Sultana et al. (2019)
35 years + Middle to end of century	8	Borris et al. (2016), Calvin et al. (2019), Crossman et al. (2013), Kumar et al. (2016), Pedde et al. (2021), Piniewski et al. (2014), Qiu et al. (2018), Sadr et al. (2020)

Sadr et al. (2020) 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 (Ofwat, 2021). 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 (Nikolopoulos et al., 2019). 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 (Sitzenfrei et al., 2010, Tomlinson et al., 2020), using probability functions or machine learning, is undoubtedly heavily data-reliant; the implications of this are discussed in Section 2.1.5.3.2.

The alternative is to assess interventions against a range of potential future scenarios that are rooted in socio-technological and political narratives[12]. Examples include those proposed by Global Scenarios Group (GSG) Futures (Global Scenarios Group, 2021), Shared Socio-economic Pathways (SSPs) (Riahi et al., 2017) and Urban Future methods (Rogers and Hunt, 2019), as well as approaches referred to in seven identified papers shown in Table 2-6.

Table 2-6: Use of future scenarios. (indicates the study was undertaken in the UK)*

Article	Number of future scenarios	Description	Horizon
Borris et al. (2016)	3	Climate change and socio-economic factors using Shared Socio-economic Pathways as basis for generation: Sustainability; Security; Intermediate	2050
Kumar et al. (2016)	4	Defined as water supply to three sectors Infinite nature; low, medium and high use of alternative resources	2100
Nikolopoulos et al. (2019)	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. (2021) *	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. (2014)	2	Stakeholder workshops generated two scenarios: sustainability eventually – environmentally optimistic; economy first – fast economic growth with intensive agriculture	2050
Qiu et al. (2018)	4	Scenarios developed to represent social, political, economic and biophysical drivers. Accelerated innovation; abandonment and renewal; connected communities; nested watersheds	2070
Sadr et al. (2020) *	4	Scenarios defined for characteristics for both society and the integrated urban wastewater systems. Market; innovation; austerity; lifestyles	2050

[12] This is discussed in more detail in Section 2.5 and Section 3.3.

In the case of Borris et al. (2016), 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 (Rogers et al., 2012). In contrast, basing decisions on near-future certainty (Li et al., 2019b) 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. (2014) 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. (2016) and Piniewski et al. (2014) describe methods that generate scenarios based on varying a limited number of factors. Ofwat (2021) also favours this approach and suggests that the factors should predominantly be viewed independently of each other. Conversely, Nikolopoulos et al. (2019), Qiu et al. (2018) and Sadr et al. (2020) 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.

2.1.5.2.2 Future Scenarios

There is a growing body of literature regarding future scenarios. Hunt et al. (2012) provide an analysis of the development of these scenarios and their alignment with GSG futures (Gallopín et al., 1997), 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 (Rogers et al., 2012). As Hunt et al. (2012) 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 (Riahi et al., 2017) which have been used by Borris et al. (2016), 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 (Environment Agency, 2017a, Environment Agency, 2017b). This very much embraces a STEEPO approach, i.e., consideration of Social, Technological, Economic, Environmental, Political and Organisational drivers of change[13]. Conversely, Ofwat (2021) 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.

[13] This is reviewed in more detail in Section 2.5.

Pedde et al. (2021) 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.

2.1.5.3 Method of Evaluation

2.1.5.3.1 Making Use of Local Knowledge

Participatory approaches, in which stakeholders and experts provide the basis for assessment (Ahmadi et al., 2020, de Brito et al., 2018, Goytia et al., 2016, Heller et al., 2014, Howarth and Monasterolo, 2017, Kumar et al., 2016, Xu et al., 2015) 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. (2016), 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. (2014). 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. (2020) 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.

2.1.5.3.2 Reliance on Data

The alternative to a participatory method is the use of quantitative analysis, simulation and modelling (Blair et al., 2019, Borris et al., 2016, Bouziotas et al., 2019, Calvin et al., 2019, Crossman et al., 2013, Gurluk and Ward, 2009, La Rosa and Pappalardo, 2020, Li et al., 2019b, Nguyen-Viet et al., 2009, Nikolopoulos et al., 2019, Piniewski et al., 2014, Qiu et al., 2018, Sadr et al., 2020, Sitzenfrei et al., 2010, Sitzenfrei et al., 2014, Song et al., 2018, Sultana et al., 2019, Tomlinson et al., 2020, Yu and Lu, 2018). Additionally, Blair et al. (2019) 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 (Ahmadi et al., 2020, Bouziotas et al., 2019, Calvin et al., 2019, Gurluk and Ward, 2009, Kumar et al., 2016, Nikolopoulos et al., 2019, Piniewski et al., 2014, Sitzenfrei et al., 2014, Tomlinson et al., 2020, Wada et al., 2017). Furthermore Hunt et al. (2016) 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 amount of reliable data to generate predictions (Blair et al., 2019, Piniewski et al., 2014, Qiu et al., 2018).

Existing data, in particular environmental data, are often the basis for quantitative modelling (Blair et al., 2019, Borris et al., 2016, Crossman et al., 2013, Li et al., 2019b, Qiu et al., 2018, Sadr et al., 2020, Song et al., 2018, Sultana et al., 2019, Yu and Lu, 2018). 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 (UKEOF, 2008) 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 (Qiu et al., 2018, Franco et al., 2018), 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. (2013), 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 (Greenpeace, 2019).

Using historic environmental data to act as a basis for future extrapolations (Blair et al., 2019, Crossman et al., 2013, Li et al., 2019b, Song et al., 2018, Sultana et al., 2019, Ofwat, 2021), 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 (United Nations, 2020, IPCC, 2021).

There is frequent application of climate models in future predictions (Calvin et al., 2019, Crossman et al., 2013, Kumar et al., 2016, Piniewski et al., 2014, Wada et al., 2017), although Howarth and Monasterolo (2017) 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 is available, and how it can be used in future predictions. There has, however, been some effort to mitigate the uncertainty or unavailability of environmental data (Makropoulos et al., 2018, Nguyen-Viet et al., 2009, Nikolopoulos et al., 2019, Sitzenfrei et al., 2010). 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.

2.1.6 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 localised 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.

2.2 Environmental justice

The systematic review determined the direction of the research and its validity in progressing current understanding. Further, and ongoing, reviews were conducted to ensure robust and relevant incorporation of the latest understanding of key concepts within the research. The first of these being environmental justice.

2.2.1 A framework and a movement

Environmental justice formed as a movement in response to recognition of the correlation between environmental degradation and social inequity (Agyeman et al., 2002). A grassroots movement, with strong associations with the USA, this contrasts with sustainability which is considered a top-down approach to assessments and policy formulation (Neal et al., 2016). For this reason it may be assumed that these concepts are synonymous arising from different schools of thought to a similar end position (Menton et al., 2020). This is not the case, the following discussion will consider the differences in these concepts.

Sustainability has gained traction as a goal; there is global cooperation, as exemplified by the UN Sustainable Development Goals (United Nations, 2015) and a considerable body of literature concerned with sustainability has formed (for example Kebede et al. (2021), Mahmoodi et al. (2021), Roobavannan et al. (2020), Tippett (2005)). Sustainability is seen as a progression of reliability and resilience (Sadr et al., 2020) with each acting as a precursor for the next. Discussion of resilience as a goal has posed the question resilience 'of what?' and 'for whom?' (Givens et al., 2018), these views could equally be posed for sustainability (Agyeman and Evans, 2004).

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): "*meeting the needs of the present* *without compromising the ability of future generations to meet their own needs*." 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 (Rogers, 2017).

Whilst this definition is considered to have an implicit reference to justice and equity (Agyeman and Evans, 2004) its progression into the Sustainable Development Goals links sustainability with development and as such assumes sustainability can be congruent with a growth economy, and growth in Gross Domestic Product (GDP) (Menton et al., 2020). Therefore, inherent to the definition of sustainability and its embedment into sustainable development, is the concept that this should also lead to growth. Growth is typically strongly linked to environmental degradation (Castellano et al., 2007, Mellander and Jordan, 2021) and attempts to decouple GDP growth from environmental harm have either not been universal (Plappally and Lienhard, 2012) or they have occurred following a peak in GDP-linked environmental degradation as depicted by the Environmental Kuznets Curve (Ahmad et al., 2021, Zhou et al., 2021). Additionally, the potential for impacts to disproportionately affect some parts of society, especially those already disadvantaged is not fully recognised and embedded into the policy approach (Agyeman et al., 2002). Associated with this recognition of the balance of environmental and social impacts is a requirement to consider values beyond direct economic and monetary impacts (Dasgupta, 2021). Including how these extend both within and between communities and globally for example in the consideration of virtual water.

Some discussion of justice considerations places this as a step forwards from sustainability (Shrimpton et al., 2021), however others (Menton et al., 2020) have posited that environmental justice is the pre-requisite for sustainability and that rather than decoupling economic growth and environmental impact there should be a shift to sustainable degrowth that recognises the intersectionality of injustices facing marginalised groups. This equates with the view that addressing sustainability is focused on the symptoms, and it is not until the causes (i.e. social injustices) are recognised and incorporated into assessments can the outcome be truly sustainable (Agyeman et al., 2002).

The environmental justice movement formed as a means of framing a response to the conflation of social inequity and environmental degradation issues, it moves beyond the distribution of environmental benefits and disbenefits to looking at the causes of environmental disbenefits and removing them at source (procedural or process justice) (Agyeman et al., 2002). This is in line with Agyeman and Evans (2004) definition of 'just sustainability'. Due to the nature of environmental justice as a grassroots movement the definitions are varied in their detail:

" Environmental justice is defined by Bullard (1996) that all people and communities are entitled to equal protection of environmental and public health laws and regulations" (Zhu et al., 2023)

This is echoed in the definition adopted by the US EPA:

" The fair treatment and meaningful involvement of all people, regardless of race, color, nationality, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (US EPA, 2024)

The association with impacts relating to human use and benefits aligns with the growth in consideration of ecosystem services (Costanza et al., 2017). However, this fails to appreciate the intrinsic value of nature beyond its value to humans. This is more aligned with practices of indigenous communities and a movement towards considering legal personhood of natural features as a method of protection beyond the value of nature as a provider of services to humans (Clark et al., 2018, Smith, 2017, Smith, 2021, Willems et al., 2021). This viewpoint is encapsulated within the definition below which will be adopted throughout this study:

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

Whilst sustainability is context specific, and the prioritisation of requirements becomes context specific, the underlying drivers of justice are universal (Agyeman et al., 2016). Therefore, the concept of universal underlying questions to drive assessments routed in environmental justice is validated. Moreover, discussion and consideration of environmental justice needs to be cognisant of power dynamics and structural conditions (Menton et al., 2020). The generation of system maps and visualisation tools enables transparency and creates opportunities to identify where power structures may be exacerbating injustices.

2.2.2 Environmental justice and water in the literature

The relationships between justice and impacts are complex (Agyeman et al., 2016), as social injustice is more likely to lead to decisions which exacerbate and increase harmful environmental impacts for communities experiencing marginalisation in a number of other forms (Canfield et al., 2023, LeFevre et al., 2023). For example, environmental degradation and consequent public health impacts disproportionately impact populations with substantial ethnic minority or deprived populations, for example; tainted tap water in Flint, Michigan, USA (Agyeman et al., 2016).

Consideration of environmental justice in the literature has included the concept in a broad sense, including definitions, inclusions and exclusions (Agyeman et al., 2016, Menton et al., 2020, Neal et al., 2014). Specific applications have focused on a particular aspect of justice; distributional, procedural, recognitional and capabilities. This has been completed within discrete topics; flooding and sea level rise, climate change, socio-ecological systems, water governance and water access and privatization concerns (Canfield et al., 2023). It is notable that the academic literature is somewhat biased in the production of articles for and by academics thereby reducing the voice of other sectors and communities, including indigenous communities, leading to a increased relevance and importance of considering grey literature (Canfield et al., 2023).

Water and concepts of justice are wide ranging and intersectional, with multiple forms of application of justice concepts, and water forming multiple roles across human and non-human users as well as 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.

Consideration of justice, and overcoming inequity has been posited as an important element in the consideration of water reuse schemes which are currently scarcity driven, rather than considering the additional social, fairness and equity benefits (Duckett et al., 2024). The inclusion therefore of wider values in public discourse changes the perception from focus on the ‘yuck’ factor of water reuse, to the attractive nature of positive environmental action, including public ownership of that action (Duckett et al., 2024). This effect is also apparent in the success of payment for ecosystem services schemes, where inclusion of community prioritisation and established community engagement improve the success of schemes (Bremer et al., 2023).

There is increasing discussion of the requirement for 'commons' to be de-privatised in the current global wave of non-capitalist movements (Weber et al., 2019) and the requirement for environmental justice considerations to be central to the governance of water. However, it is not a necessary condition of non-privatised water services that these are just. The privatisation of water in the UK coincided with, and was spurred on by, growing regulatory requirements to reduce environmental pollution from sewage effluent (Beecher, 1997, Byatt, 2013). This increasing level of regulation resulted in improving environmental standards (Naden et al., 2016) despite the commonly-held understanding that privatisation would lead to lowering standards (Weber et al., 2019). Indeed, the assertion that de-privatisation would lead to significant environmental improvements does not account for either the role of regulation and policy, or availability of funding to initiate changes. Therefore, the nature of privatised versus public services is not the deciding factor on environmental or social outcomes, instead these are governed by the political will to determine that improvements are required and the provision of suitable levels of funding to enable interventions to be enacted. This does not reduce the impact of the environmental justice movement, but focuses the movement on outcomes, rather than ownership. That said, funding mechanisms and payment for water services is subject to justice considerations which are more closely linked to ownership and service provision mechanisms. This is of particular note when considering future scenarios in which there could be drastic shifts in both governance and ownership models.

2.3 Context: the value of water[14]

Connected to the issue of justice and how benefits and harms are distributed across human and non-human users, is the value ascribed to water as this so often reflects the level of priority placed on protections. This is highly context dependent and related to organisational and decision-making structures around the use and custodianship of the water environment as well as individual responsibility and action.

2.3.1 The value of water

The issue of the value of water can be traced back to Adam Smith's 1776 The Wealth of Nations. Smith noted the diamond-water paradox in which greater value is ascribed to the non-essential diamond rather than to life-preserving water (Investopedia, 2021). This view persists although at a local scale overexploitation has been observed to increase public perception of value (Roobavannan et al., 2020). Economists and others have theorised over different approaches to considering value and the influence this has on consumption. Numerous approaches could be used to influence the consumption of water at both industrial and domestic user scales. These range from raising awareness through education and public campaigns, to fitting water saving devices such as in Australia during the Millennium Drought (Rogers et al., 2020) and South Africa in Cape Town's Day Zero (Booysen et al., 2019, Gittins et al., 2021). Alternatively, more overt methods can be used to directly influence consumption either through assigned quotas (Shi et al., 2014) or markets and pricing mechanisms (Brookshire et al., 2004, El-Khattabi et al., 2021, Olmstead and Stavins, 2009). Additionally,

[14] This section is adapted from BOWMAN, B. M., ABBOTT-DONNELLY, I., BARSOUM, J.-F., WILLIAMS, P., HUNT, D. V. L. & ROGERS, C. D. F. 2023. The water pivot: transforming unsustainable consumption to valuing water as a resource for life. Frontiers in Sustainability, 4.

given that water is traded between nations in an embedded form (Roson and Damania, 2017, Serrano and Valbuena, 2021, Wang et al., 2018) and through transboundary watercourses (Plappally and Lienhard, 2012, Yu and Lu, 2018), the global interaction of water policy becomes an area of potential sensitivity. Therefore, different cultural contexts, and desired goals, are likely to influence the success and range of impacts of the measures that have been developed and implemented to control consumption. How these fit in a global context is also important.

Assigning quotas, or command and control methods, can be used to facilitate efficient, predictable sharing of resources (Shi et al., 2014). They are considered to be quicker and easier to implement compared to exploring the use of alternative water resources (Hunt and Shahab, 2021), including recycling (Blackmore et al., 2020) or allowing market forces to influence multiple users of the resource (Munasinghe, 2010). However, studies have also found command and control methods to result in greater economic losses and therefore be more expensive to society (Luby et al., 2018, Olmstead and Stavins, 2009).

Restrictions to water consumption has impacts across society, impacting the nature of agriculture and goods production with subsequent equity and greenhouse gas emission implications at local and global scales. For example by impacting crop selection and agricultural irrigation practices (Castellano et al., 2007, Shi et al., 2014), which could have economic effects (Shi et al., 2014, Yan et al., 2020), or promote a transition from domestic production to imported goods (Luckmann et al., 2016). Water efficiency measures are frequently reliant on the adoption of technological changes both at the domestic scale and beyond. This has inherent risks in leading to technological lock-in (Markolf et al., 2018), has the potential to limit innovation (Olmstead and Stavins, 2009) and not lead to expected savings due to behavioural changes (Hunt and Rogers, 2014, Hunt and Shahab, 2021, Olmstead and Stavins, 2009). It also has the potential to increase inequity due to a requirement for new technology to meet the restriction. It has been suggested that a palatable approach would be the combination of technology with behavioural approaches (Hunt and Shahab, 2021, Murwirapachena, 2021), which could align with market-based policies akin to other environmental initiatives (Gugler et al., 2021).

A market-driven and liberal policy has been shown to increase welfare (Luckmann et al., 2016); indeed there are many studies based on a market- and price-driven approach (Bierkens et al., 2019, Bjornlund and Shanahan, 2015, Brown, 2006, Castellano et al., 2007, Luby et al., 2018, Luckmann et al., 2016, Reddy et al., 2015, United States Environmental Protection Agency, 2002). However, a difficulty arises in that water is a provider of both private and public goods and services, and as such markets are considered to be poor providers of information on either the value of water or optimal allocation (Reddy et al., 2015). Options to use payment for ecosystem services have been discussed (Pissarra et al., 2021) in which downstream users of water systems compensate headwater farmers to adopt agroforestry and sustainable forestry practices. The conversion of environmental impacts into a monetary variable for inclusion in economic analysis (Hatamkhani et al., 2023) risks the commodification of nature (Farley and Costanza, 2010) and excludes from the assessment further impacts to the community. Alternatively, a multi-capitals approach to assessing value is gaining traction (Acosta et al., 2020, British Water, 2022, Dasgupta, 2021, Fenech et al., 2003, Kanakoudis et al., 2011, Mellander and Jordan, 2021), which allows a complete understanding of value to be considered alongside fiscal measures.

The price elasticity, namely the price difference needed to elicit change in consumption, is variable based on the timescale under consideration for impact (Scheierling et al., 2006) and the sector, along with the ability to pay increased prices (Berbel and Expósito, 2020, Olmstead and Stavins, 2009), or cope with interruptions in supply (Brown et al., 2019). Therefore the success of price measures is mixed and highly dependent on the price elasticity of water use (Shi et al., 2014, Kertous et al., 2022). At the domestic scale, water use is generally considered to be inelastic (Luby et al., 2018, Olmstead et al., 2003), and therefore to effectively influence water consumption different factors become significant for different users and these should consider cultural contexts.

A difficulty arises when considering the value of water when we contemplate the diversity of source water quality (Brown, 2006, Piper, 2003), varied uses of water within society including agriculture, industry and municipal use (Bjornlund and Shanahan, 2015, Blackmore et al., 2020, Brown, 2006, Castellano et al., 2007), the cultural significance of waterbodies (Auerbach et al., 2014, López Moreira M et al., 2018, Shriver and Peaden, 2009) and users within nature. This heterogeneity means that the water market does not lead to a single price for water (Brown, 2006); indeed when water is considered a public good it typically has a lower price associated with it (Shi et al., 2014). However, much of the discussion (Bierkens et al., 2019, Bjornlund and Shanahan, 2015, Brown, 2006, Scheierling et al., 2006) is focussed on the shadow price of water and the use of markets at abstractor, or organisational, level and not how this translates to the domestic consumer. This reflects a view of water as an economic good rather than a public good and human right. Although in many ways analogies may be sought between water pricing and carbon pricing, in that markets in both cases could be used as mechanisms to change environmental impacts, it is in this area that the two diverge. Whereas a unit of greenhouse gas, for example a kilogram of carbon dioxide equivalent, has a similar climate change impact anywhere in the world, water has an almost infinite number of possible prices depending on local conditions, availability and requirements.

There are justice considerations (as discussed in Section 2.1 and 2.2) when setting water prices to reduce consumption. If the difference in shadow price compared to the current price is too great this can have inequitable and unjust economic and societal impacts. There is a risk of inter-sectoral inequity when applied at the organisation level (Shi et al., 2014) and community level inequity (Heino and Takala, 2015, Luby et al., 2018, Ntengwe, 2004, Olmstead and Stavins, 2009, Kertous et al., 2022) if the pricing structure is established without justice principles at the forefront. Furthermore there are additional restrictions in the implementation of changes to water pricing due to institutional rigidity within the political economy and governance systems (Mumssen et al., 2018).

Price measures to discourage consumption inevitably lead to increased revenue in the short-term (Olmstead and Stavins, 2009); which body becomes responsible for these sums is uncertain and there are justice considerations to this. There are options to reduce poverty through the redistribution of wealth and provision of additional societal benefits (Luckmann et al., 2016, Olmstead and Stavins, 2009). Therefore, although pricing and market mechanisms are frequently viewed as the most effective method of reducing consumption, they are not methods without implications for fair and equitable use of water.

2.3.2 Pricing structures and availability

At a local level, reliability of supply is a key factor in consumer willingness to pay for water alongside awareness of water quality and knowledge of water service. However this willingness to pay is tempered by the ability to pay (Adeoti and Fati, 2022, Ahmed et al., 2022, Ntengwe, 2004). Where infrastructure and regulation are sufficiently developed, such that access to clean water and sanitation is locally universal, understanding of the volume of water consumed, the price of this water and subsequently the value it provides can be seen to be lacking. This is observed throughout the population, including amongst an environmentally aware sample group, where there is frequently little recognition of either the amount of water used, or the cost of that water (Heino and Takala, 2015, Hunt and Shahab, 2021, Lucio et al., 2018).

2.3.2.1 Centralised funding: example from Ireland

Water supply in Ireland has undergone some recent changes; previously delivered through local government and funded via central taxation, water services are now delivered across the country through Irish Water. Originally planned to be funded through direct billing of the 80% of the population that is provided with centralised services, public outcry (Rodriguez-Sanchez et al., 2018) led to an agreement that government subvention would provide baseline funding, equivalent to 74% of revenue needs (2019-2024) (UISCE Eireann Irish Water, 2018). Excess water use (over 213m^3 per year for a 4-person household, equivalent to 146 l/person/day) is charged, under a 'polluter pays' principle, with a cap on the total charge per year (UISCE Eireann Irish Water, 2021). These events demonstrate the difficulty in changing water pricing structures due to rigidity in the political economy and in public acceptance of changes.

Due to the lack of direct billing of water there is an argument that the cost of water becomes hidden and there is a disconnection between domestic water use and the costs associated with water use, including environmental impact and thereby the value of water. The per capita consumption of water in Ireland is currently comparable to the rest of northern Europe (Bowman et al., 2023). It remains to be seen whether domestic consumption remains constant in Ireland at a time when there are widespread campaigns to reduce consumption in comparable countries, or if this disconnection leads to levels of demand from domestic users in Ireland remaining constant.

2.3.2.2 Direct billing: example from England and Wales

Investigations by the Consumer Council for Water (CCW) have indicated that 10% of households regularly struggle to pay bills (Consumer Council for Water, 2021a), therefore fairness of bills is a concerning issue. CCW defines water poverty as water bills totalling more than 5% of household income after housing costs have been paid; this is comparable to the UN recommendation of water services costing less than 3-5% of household income, although noting that this is an imperfect metric (United Nations Childrens Fund (UNICEF) and the World Health Organisation, 2021).

Bills in England and Wales average at £412/household/year (2022/2023 data (Water UK, 2024a) which is 1.16% of the median income level across the UK; however for the more vulnerable in society, i.e., those on minimum wage, the national living wage, or Universal Credit the picture changes. For those households, water bills rise to between 3% and 11% of income depending on age, the number of people in the household and the income level[15]. It is estimated (Consumer Council for Water, 2021a) that 6% of households in England and Wales

[15] Since publication of BOWMAN, B. M., ABBOTT-DONNELLY, I., BARSOUM, J.-F., WILLIAMS, P., HUNT, D. V. L. & ROGERS, C. D. F. 2023. The water pivot: transforming unsustainable consumption to valuing water as a resource for life. *Frontiers in Sustainability,* 4. the costs of water services and income levels have changed. This section has been updated with the latest available data which is for the year 2023

spend more than 5% of income on their water bill. Contrast this with the 10% that views bills as unaffordable and it appears that there is a discrepancy between the threshold for water poverty and the value which the public ascribes to water. This could be related to the perceived abundance of water in the country (Praskievicz, 2019), or that water was delivered as a nationalised public service within living memory of the majority of the population.

Nevertheless, it is evident that at a national scale, current water bills are inequitable in the degree of impact they have. In addition, the mechanism of customer-driven adoption of water metering is increasing the financial burden to those less able to pay, and bill payment support is geographically varied (Bayliss, 2014, Consumer Council for Water, 2021a) thereby increasing inequity across the country.

2.3.2.3 Rising block tariffs and seasonal charging: example from USA

Examining water prices in the USA, it becomes apparent that there are vast differences in pricing strategies. Luby et al. (2018) found a negative relationship between water price and water scarcity that persisted when accounting for variation in the cost of living. Despite water charges in Phoenix being lower than across much of the USA, the policy of enabling affordable water for essential inside use with increased charges for higher water users, including seasonal variation of rates, has gained support as a method of reducing consumption. However, this is coupled with indirect unjust impacts as higher water charges have a greater influence over behaviours of less affluent parts of the community. In this case this is exhibited as converting lawns to desert landscaping whilst more affluent areas maintain existing behaviours and high water demanding lawns and plants. This exacerbates the urban heat island effect and inequitably impacts the community (Sorensen, 2019, Zhu et al., 2023).

2.3.3 Water pricing strategies

The implementation of payment for water services is linked to the political ideology of that time and place, this has implications for the value society places on water. It also has justice implications due to the potential for variable impacts across society. These external structures and framing of access to resources has lasting impacts on cultural evolution and the consensus on acceptable behaviours and attitudes (Farley et al., 2020).

Whilst the value of water is commonly defined by the economic value it generates, this fails to recognise the wider values that water provides unless a multi-capitals, or payment for ecosystem services policy, is adopted. Value is also frequently biased towards human prioritisation over ecological benefits. How the price of water impacts different communities and sub-populations means that a justice approach is needed to enable intergenerational equity and environmental, or water, justice. Moreover, the multi-faceted impacts of the water system require visualisation to enable collaborative understanding of the impacts of actions at the organisational and individual scale.

2.4 System mapping approaches[16]

To enable a shared understanding of the value of water and surface water systems the relationships within these systems require exploration. Furthermore, it is essential for cross-sectoral and cross-societal engagement that these relationships are accessible to a wide

[16] This section is adapted from BOWMAN, B. M., HUNT, D. V. L. & ROGERS, C. D. F. 2024. Visualising the surface water system. An environmental justice-led approach. Frontiers in Water, 6.

cohort, as such visualisation methods that enable a common method of communication are of considerable value.

2.4.1 Water systems mapping

Systems approaches have been gaining traction within water research over the past two decades with an upsurge in the last five 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 prioritisation across the fields of consumption, agriculture and industry, including energy generation (Givens et al., 2018, Ioannou and Laspidou, 2022). As a result, attention is on water as a resource rather than as a multifaceted system of its own and presents a *'people and resource'* centred approach. This echoes the economic view of water in pricing mechanisms.

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 visualisations (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). These 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 prioritisation of services and values influences the exploration of sustainability trade-offs at project or intervention scales (Guest et al., 2010).

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 i.e. environmental justice-led, may be useful in overcoming these barriers to representation.

2.4.2 Justice-led systems mapping

Defining the problem statement around a current need or requirement fixes the framework within current prioritisation and cultural norms. However, currently 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 UK (Mitchell, 2019, Warwick, 2012) or global (United Nations, 2015) scale.

The incorporation of local context and local conditions (Rogers, 2017) may manifest in the overall objectives, and what is considered to be the 'success' of interventions; for example, inclusions related to value generation and how these are incorporated into assessments. 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, 2017b, Hunt et al., 2012, Gallopín et al., 1997, Raskin et al., 2002) allows exploration of the system within a range of extreme, yet plausible external characteristics. This, as has been determined within the realm of urban development (Hunt et al., 2013, Leach et al., 2020, Rogers and Hunt, 2019), would enable the exploration of relationships, outcomes and impacts across potential future generations. In considering environmental justice the impacts of the system, or interventions within the system, on social equity and ecological outcomes are highlighted.

2.5 Future scenarios and their application

The importance of local context and conditions has been highlighted; however, this extends into future contexts. As such, the methods of assessment into the future require detailed consideration.

2.5.1 Development of future scenarios

The use of future scenarios, or foresight, to explore the consequences of actions taken today for future society and environmental conditions has been an area of interest in the academic literature since the latter parts of the 20th century (Borris et al., 2016, Gallopín et al., 1997, Hunt et al., 2012, Riahi et al., 2017, Rogers and Hunt, 2019). These scenarios are not predictions or forecasts, instead they are plausible yet extreme representations of future societies and systems. Future scenarios are developed through the examination of key drivers of change and develop internally consistent narratives that explore the extremes within areas of uncertainty and importance. Additionally, they are positioned far enough into the future to enable extreme differences to the current situation to be viable given sector investment periods, asset renewal cycles and changing socio-economic contexts. To this end (as noted in Section 2.1) a number of scenarios have been developed in the past 30 years that have advanced quantitative and qualitative narrative scenarios (Borris et al., 2016, Kumar et al., 2016, Nikolopoulos et al., 2019, Pedde et al., 2021, Piniewski et al., 2014, Qiu et al., 2018, Riahi et al., 2017, Sadr et al., 2020). Hunt et al. (2012) analysed scenarios that had been developed between 1997 and 2012 to determine if a set of archetypes exist that could be applied in the UK context, in this case specifically for urban redevelopment, and would prevent the need for the derivation of additional scenarios. This analysis concluded that the Global Scenario Group (GSG) scenarios that had been developed in 1997 formed a sufficiently robust and diverse range of futures to enable interpretation for an urban futures context. Since this time, the Environment Agency has developed a series of 'plausible future scenarios for the water environment to 2030 and 2050' (Environment Agency, 2017a). The basis of these scenarios has been reviewed and compared to wider global literature on future scenarios to determine the most appropriate basis for the visualisation of future relationships within the surface water system.

2.5.2 Environment Agency scenarios

The reports published in 2017 (Environment Agency, 2017a, Environment Agency, 2017b) are the culmination of analysis led by the Environment Agency (EA) and funded by the Defra Futures Partnership. A drivers, pressures, status and impacts (DPSI) analysis was employed to develop socio-economic scenarios with specific relevance to the water environment and water management in England and Wales. These were characterised using a policy, economy, social, technology, legislation, environment (PESTLE) framework. Four future scenarios are presented Uncontrolled Demand (UD), Innovation (INN), Sustainable Behaviour (SB) and Local Resilience (LR) as well as a Reference Scenario (REF) based on current activities and trends.

The scenarios presented by the EA are framed for 2030 and 2050, 13 and 33 years into the future respectively from the time of publication. The timescale here is critical as the projected dates are fixed and so the interval from analysis to 'future' is reducing as we progress from the time of publication. Additionally, other studies have stated a requirement for an appropriate timescale relative to regeneration cycles; in the case of urban regeneration this is set at 40 years (Hunt et al., 2012), however in the case of water sector systems this could extend from 40 to 100 years plus to represent the asset life of largescale infrastructure such as networks and reservoirs (Nikolopoulos et al., 2019). Alternatively, if considering the timescales for action to impact the natural environment: 20-30 years has been noted as required for natural remediation of high phosphorus in lakes (Rippey et al., 2021) or 50 years for a nitrate peak to reach chalk aquifers (Wang et al., 2011). Therefore, the timescale of futures analysis when considering the water system may need to be variable, but in almost all cases extends beyond a 30-year horizon and beyond 2050. Finally, for foresight techniques to be advantageous the future scenarios should be set far enough into the future to enable extremes to be plausible

(Hunt et al., 2012, Rogers and Hunt, 2019); it is questionable whether that is the case when the furthest future is less than the expected interval for asset renewal or environmental impacts of interventions becoming apparent.

Since publication of the EA scenarios a number of significant global events have occurred which may impact the assumptions underlying scenario development. These assumptions, and their ongoing validity are explored below:

Environmental policy

All of the EA scenarios assume a continuation of EU legislation making this an external regulating force on environmental policy in the UK. Arguably, although a possibility, this constrains the visioning of future scenarios compared to the realm of plausible extremes.

Behavioural patterns

The Covid-19 pandemic has changed daily patterns with fewer people working from offices every day affecting domestic water consumption trends and the impact of water-saving devices in office buildings (Abu-Bakar et al., 2021, Cahill et al., 2021, Dobson et al., 2021). This is a subtle change, however a growth in hybrid working could lead to changing living patterns and a movement away from suburbs. Some degree of variation in urbanisation and population locations is incorporated in the scenarios enabling incorporation of this uncertainty.

Global stability

Global events such as the war in Ukraine have implications across the UK, not least due to food and energy availability linked to global trade dependencies, and linkages to the water-energy-food nexus (Proctor et al., 2021). However, the scenarios set out by the EA do not incorporate global stability or instability and the impact that would have indirectly across the water environment.

Climate change

Similarly, the impacts of climate change are considered to be constant at the global scale with reductions in GHG emissions within the UK not having a global impact nor being matched globally. However, since publication there has been building consensus over the scale, impact and cause of carbon emissions (IPCC, 2021) and global commitments to action to reduce emissions in order to limit the impacts of carbon emissions (United Nations, 2023a). At the current time there is still considerable scope for global action to fall short and take too long to abate climate change. However, to assume in all scenarios that climate impacts will occur due to a lack of coordinated global action seems pessimistic whilst at the same time the scale of impacts within England and Wales, although not expanded upon in detail, do not match the scale of impacts currently under discussion (UK Government, 2022b) resulting in this element being potentially incompletely explored across all scenarios.

Role of the economy and political economy

Finally, the scenarios have been developed using a PESTLE approach; within the policy and economic elements of this a strong economy is seen as one with GDP growth. There is some variation in an allowance for the inclusion of ecosystem services in decision-making in the Sustainable Behaviour scenario however alternative economic models such as those incorporating planetary boundaries (Raworth, 2022) are not considered.

Examining the assumptions borne out in the scenarios developed by the Environment Agency demonstrates that a broad view of possibilities and a timeframe far enough into the future is required to allow the freedom to extend scenarios into the extremes. This element is seemingly restricted within the Environment Agency futures; however, this is vital to the use of foresight techniques. Indeed, comparison of the EA future scenarios with GSG scenarios on the axis of cooperation and prioritisations (Figure 2-7) demonstrates that the extremes laid out within GSG futures scenarios, are not transferred into EA futures, the latter of which more closely align with 'conventional worlds' rather than extending into 'Great transition' or 'Barbarism' world end-states[17]. This arguably provides an optimistic view of potential futures and does not include the possibility of a social vision that has succumbed to fragmentation, environmental collapse and institutional failure. This is likely a consequence of the more limited timeframes under consideration between the two approaches and the aspiration of GSG to include extremes whereas EA futures prioritise plausibility within current norms. Therefore, GSG envisage profound transformations within the slow dynamic structures within socio-ecological systems which are not fully explored in EA futures.

[17] Whilst 'conventional worlds' align with recognisable socio-economic contexts that are characterised in the extreme, 'barbarism' scenarios include the possibility of destabilisation of societal structures whilst 'great transition' scenarios represent a shift away from historic trajectories in response to planetary changes.

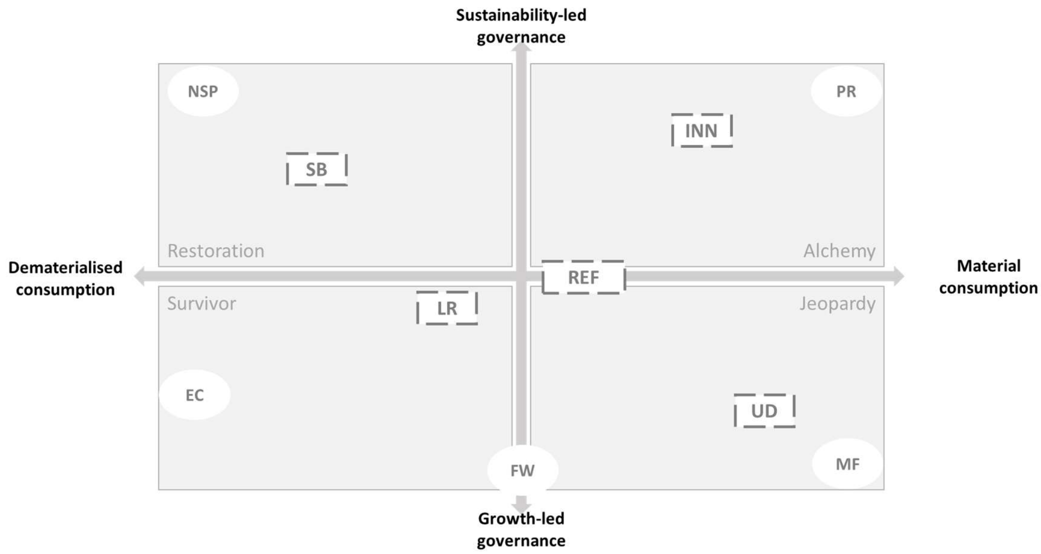


Figure 2-7: Scenarios plotted against governance and consumption axis, modified from (Environment Agency, 2017b). Dashed boxes indicate relative positions of EA water scenarios to 2030 and 2050 (Environment Agency, 2017b). Circles indicate relative positions of GSG global scenarios (Gallopín et al., 1997, Hunt et al., 2012).

2.5.3 Integration of future scenarios into this study

This analysis has demonstrated that the EA scenarios do not represent the full range of potential extreme future scenarios which are encompassed by the archetypal GSG future scenarios. As such this study will build on four of the global scenarios to incorporate alternative socio-economic contexts. The two 'conventional worlds' Market Forces (MF) and Policy Reform (PR) as well as one of the 'Barbarism' scenarios; Fortress World (FW), and one of the 'Great transitions'; New Sustainability Paradigm (NSP)[18]. These will be discussed in more detail in Section 3.3. These scenarios are set in the year 2100; far enough into the future to make changes to the socio-economic context plausible.

[18] Four future scenarios are chosen as this is considered the maximum that can be effectively engaged with whilst maintaining rigour (Hunt, 2012). Environmental Communalism (EC) and Barbarism (B) are not included further, these scenarios are less well-adopted throughout the literature and within the GSG development of scenarios. This possibly reflects these scenarios being further removed from global experience.

2.6 Indicators as tools to enable fair assessments

Considering the relationships within the water system, and methods of analysing this in alternative futures give confidence to the ability of an intervention to perform the desired functionality. However, alongside this there is a requirement to be able to assess systems in comparative ways in order to build a comprehensive understanding across a landscape. Indicator systems, as a combination of indicators, metrics and benchmarks, are a mechanism through which comparative assessments can be made of both direction of travel as well as status relative to a target (Hunt et al., 2008).

2.6.1 The role of indicators in water management

Mechanisms to embed concepts of justice within water management are emerging (Agyeman and Evans, 2004, Agyeman et al., 2016, Bremer et al., 2023, LeFevre et al., 2023, Rockstrom et al., 2023) and mechanisms to provide quantifiable analysis of outcomes, such as indicators, would act as enablers. Indicators can have two main operating functions: to specify thresholds for action to be initiated, as put forward by Murgatroyd and Hall (2021); or alternatively to act as benchmarks to strive towards, as is the case with the Water Sensitive Cities Index (Rogers et al., 2020). In this latter role they are essential and ubiquitous across several sectors including urban development (Boyko et al., 2012, Leach et al., 2019).

Reliance on water for consumption, agriculture, energy generation and industry has led to a large body of literature concerned with sustainable water resources management (SWRM). A large sub-section of this research develops and applies modelling approaches to determine:

- the most advantageous uses or availability of water in a given area - e.g. input/output models (Li et al., 2019b), resource allocation model in Python (Tomlinson et al., 2020), Epanet (Sitzenfrei et al., 2014), Water Evaluation and Planning system; WEAP (Hatamkhani et al., 2022), Stormwater management model; SWMM (La Rosa and Pappalardo, 2020), Urban Water Optioneering Tool; UWOT (Bouziotas et al., 2019, Nikolopoulos et al., 2019)

- the use of quantitative models to determine the quality impacts of certain interventions and events - e.g. Integrated catchment model; INCA (Crossman et al., 2013) and WinSLAMM (Borris et al., 2016), and
- predictions of water availability in different climate futures (e.g. Epanet (Sitzenfrei et al., 2014), WEAP (Hatamkhani et al., 2022), SWMM (La Rosa and Pappalardo, 2020), DynaVibe (Sitzenfrei et al., 2010).

Equally a substantial portion of the literature is concerned with indicators and metrics to quantify the current situation enabling comparison between areas and standards to strive towards. Of these, two of the foremost used for widespread assessments are the Sustainable Cities Index (Arcadis, 2022) and the Water Sensitive Cities Index (Rogers et al., 2020).

The Sustainable City Index (Arcadis, 2022) provides a basis of comparison across the pillars of economy (profit), society (people) and environment (planet) with a recent focus on the relationship between profit and prosperity. The 2022 ranking shows that US cities dominate the ‘profit pillar’ assessment, however this is not reflected in a high overall ranking due to the impacts of low people and planet scores. This draws a conclusion that cities established to maximise traditional economic growth outputs do not enable sustainability, or justice, to be fully realised. However, 80% of cities (e.g. Copenhagen, Tokyo, Edinburgh) in the top half of the profit ranking are also in the top half of the overall Sustainable Cities Index, thus demonstrating the link between financial profitability and the ability to support communities and the environment on which they depend.

An alternative standard is the Water Sensitive City in which socio-political drivers have promoted inter-generational equity and resilience to climate change, leading to water sensitive values and behaviours enabled by urban design and multi-functional infrastructure (Rogers et al., 2020). This demonstrates alignment with environmental justice objectives (Menton et al., 2020, Mitchell, 2019, Neal et al., 2016) yet constrains the assessment to judicial boundaries e.g. a metropolitan area or municipality. Water systems can be delineated in multiple ways depending on the focus and remit of the assessment. As such, a surface water system, in contrast to a Water Sensitive City, may extend across municipal, regional and national boundaries. In so doing, it may incorporate a wide range of geographical, political, cultural and behavioural differences that impact relationships across the water system at environmental, social and economic scales.

Perhaps in line with the objective of optimising resource use, or historic rights systems, such as the riparian doctrine (Praskievicz, 2019), there has been a focus on framing water management around the needs of the population. This prioritisation, whilst understandable from a development perspective, does not address where environmental degradation is reaching an ecological turning point (IPCC, 2021, United Nations, 2020). The surface water system is not only a source of water supply it is a multi-functional environment that provides habitats and contributes toward ecosystem services (Costanza et al., 2017, Farley and Costanza, 2010). If degradation continues to the point that self-repair is limited, water as a resource effectively becomes non-renewable with widespread damaging implications for the environment, society and the economy (Dasgupta, 2021). Putting the water system at the centre reflects the view that an economy is reliant on a healthy, functional and prosperous society which is, in turn reliant on a healthy, functional and prospering environment.

2.6.2 Implementing indicators effectively

National assessment frameworks such as the Outcome Indicator Framework (Ofwat, 2024e) provide an overview of trends across a range of factors. Although this may be able to guide national strategy it is not suitable for completing assessments at either a regional or landscape scale. The alternative approach of quantitative assessments and models is restricted due to the underpinning environmental data being fragmented and disjointed within the UK as discussed in Section 2.1.5.3.2. This does not provide the geographical and temporal granularity required for reliable assessments (Franco et al., 2018, Qiu et al., 2018). Thus, the applicability of quantitative modelling methods is undermined as increasingly large data sets are needed to facilitate and justify their implementation. More often-than-not, this causes delays in the application of these methods until sufficient data is collected. Initiatives are underway to generate a standardised framework for multiple-source data collection (The Rivers Trust, 2021, Moolna et al., 2020, Thornhill et al., 2019), however this is not yet fully tested, accepted or embedded.

Further complexity in the application of modelling approaches is the uncertainty with which future predictions can be made (Howarth and Monasterolo, 2017, Rogers et al., 2012, Speight, 2015). However, all assessments, be they modelling or indicator-based, have a requirement for the data to be available and representative across the full range of areas within which they are applied. Without this there would be difficulties in assuring that decision outcomes and actions were applied appropriately or fairly. In cases where the assessment is used to determine investment or interventions that would improve water quality or availability there are clear implications when the data on which these decisions are based, does not fully represent the impact area.

Indicators that support assessments utilising an environmental justice lens are an enabler to integrating environmental and inter-generational social justice views. Application requires assessments to incorporate indicators from a range of perspectives and do so equitably and relevantly. Existing indicator-based assessments take what might be termed a *'people and resource'* centric view of, and approach to, water management. Contrastingly an environmental justice approach would centre on water as a system and examine human and other-than human relationships across this system to assess and reduce barriers to equity.

2.7 Literature landscape in the context of this research

Whilst much of the literature utilises concepts of sustainability this leads to concerns over sustainability 'of what?' and 'for whom?'. Originating from grassroots action related to synergies in environmental degradation and social injustice, the environmental justice movement is developing into an area of active research within academic studies. Within practice, and in particular UK water regulatory systems, the inclusion of justice themes is implicit rather than explicit. However, there is evidence of entrenched injustice in outcomes related to the water system, for example in the costs associated with water services (Section 1.4.2 and Section 2.3.2, this is further expanded in Sections 4.1.2 and 4.4.3). Therefore, there is a need to recognise this requirement more fully and overtly.

Connected to the embedment of environmental justice is a requirement to better understand the system and its relationships and interactions across different users. The inland surface water system is complex and adaptive with non-linear responses thereby lending itself to system mapping approaches. Systems mapping is particularly relevant where certain actors, such as nature, do not have their own voice, instead by visualising impacts the consequences of action are made more apparent and transparent. Similarly, the use of impact or outcome driven assessments, using environmental justice as a framework, enables the difficulties of representation to be overcome.

Within these assessments an understanding of the potential impacts into the future are required, this is supported by developing understanding of relationships into diverse, and extreme, alternative future scenarios. Future scenarios have largely been determined to have converging themes that align with GSG scenarios. Whilst these represent a global view of futures, they require assessment and detailed consideration to understand the impacts within a given country, region or system. A specific review of scenarios developed by the Environment Agency for scenario-based assessments has ascertained that these do not represent the extreme, yet plausible, futures put forward by the Global Scenarios Group. Indeed, in the seven years since publication the regulatory context which is assumed as a constant is no longer guaranteed. As such, there is a requirement to explore how future scenarios would manifest at the inland surface water system scale, including how this would modify relationships and the ability of the system to either support or hinder movement towards environmental justice.

System mapping is a useful tool in the visualisation and exploration of impacts. Similarly, indicators are a valuable method of consistently assessing a system against common criteria making both of these tools highly relevant to decision-support tools. Indicators are well-used within both academic assessments and in practice, however these assessments are typically people and resource centred. In viewing water as a resource, it is considered predominantly as an economic good, as such the intrinsic value of water to the natural environment and its role as a public good becomes diminished. An alternative approach is needed to enable assessments using indicators that is environmental justice-led and in so doing moves away from predominantly representing water as a resource.

This study aims to develop tools to support an environmental justice-led approach to understanding and managing surface water systems. Visualisation methods are required to enable multi-sector engagement with a complex system that performs a multitude of functions. Paired with indicators this would enable comprehensible assessments and the representation of knowledge that incorporates multiple data-sources and is accessible across society.

3 METHODS

This chapter outlines the methods utilised in the development of system maps, a conceptual model, environmental justice-led indicators and visualisations of the surface water system to incorporate environmental, social and economic views within an environmental justice-led framework. The approaches utilised included systems approaches, specifically the use of system mapping and the generation of a causal loop diagram to act as a conceptual model and enable meaningful analysis of the key points of interaction within the system. This study has utilised a multi-stage approach based on the implementation of systems mapping and validation using expert knowledge which is described in Section 3.1. The remaining sections of this chapter outlines the methods used for each objective (Table 3-1).

The methods applied to generate system maps to explore relationships across the surface water system are described in Section 3.2. This was facilitated through the use of an online system mapping software and validated through focus group discussions. Section 3.3 details how future scenarios have been utilised to understand how these relationships may change into the future. This understanding of relationships both now and into the future have been used to identify key relationships and points of interaction as described in Section 3.4. Developing this understanding has enabled the generation of a causal loop diagram which forms a conceptual model of the system (Section 3.5). The key relationships and points of interaction identified in the system maps and causal loop diagram were used to devise a series of questions from environmental, social and economic perspectives that relate to the ability of the system to thrive under the definition of environmental justice stated in Section 2.2.1. These questions enabled the completion of a justice-led assessment of existing indicators and the proposal of an environmental justice-led indicator system (Section 3.6).

The development of justice-led indicators was validated using a questionnaire and semi-structured interviews, targeted for completion by UK water sector experts. Finally, proposals were made for visualisation of system-scale indicators and application using case studies at multiple tiers of practice (Section 3.7) has assessed and demonstrated the potential impact of the research.

Table 3-1: Summary of chapter section, method and the associated objective

Method Section	Objective	Method
3.2	O1 – Explore relationships across the surface water system using a justice-led framework	M1 – Use evidence-based system mapping to explore relationships across the surface water system using a justice-led framework. Generate three perspective-driven system maps. Focus groups used for validation
3.3	O2 – Explore these relationships using future scenarios	M2 – Expand on established future scenarios to consider these at the surface water system scale. Apply these future variabilities and impacts across perspective-driven system maps
3.4	O3 – Define key points of interaction across perspectives and future scenarios	M3 – Analysis of perspective-driven system maps (including future scenarios) to define key points of interaction across perspectives and future scenarios
3.5	O4 – Refine the exploration of key points of interaction within perspective-driven system maps and across future scenarios into a causal loop diagram of the surface water system centred on the key points of interaction	M4 – Develop casual loop diagram centred on the key points of interaction
3.6	O5 – Define indicators to represent holistic concerns across the surface water system and reflect the key points of interaction	M5 – Literature analysis driven by key points of interaction used to review existing indictors and define indicators to represent holistic concerns
3.7	O6 – Application at different tiers of practice	M6 – Application at different tiers of practice

3.1 Overarching approach

The study followed a multi-stage method utilising visualisation and combined participatory and case study validation methods to generate tools and an exploration of the impacts they could have. The totality of the method may be described as in Figure 3-1. Central to the methods utilised were the adoption of systems approaches (Section 3.1.1) and validation using expert knowledge (Section 3.1.2).

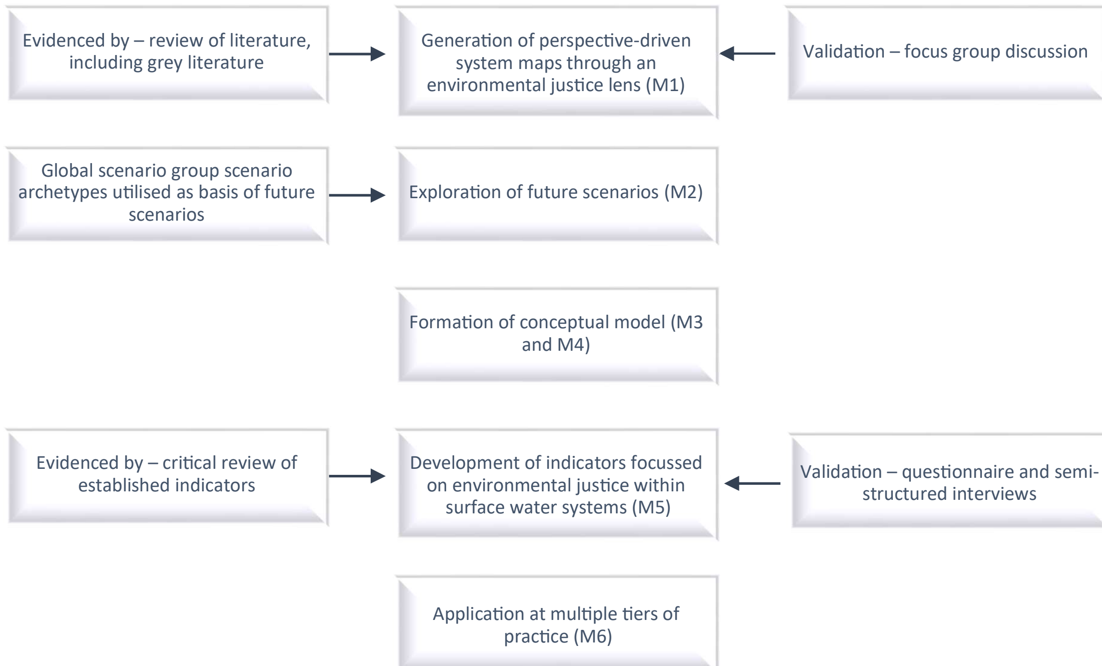


Figure 3-1: Summary of overall method applied in the study, including the basis of evidence applied and the validation method utilised

3.1.1 System approach

Systems thinking is increasingly being applied to enable the inherent complexity of Complex Adaptive Systems (CAS) to be assessed and facilitate comprehensive exploration of consequences. Within this approach system mapping acts as an enabler to better visualise 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 visualisations (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).

Kumu relationship mapping software (https://kumu.io/) is a method of visualisation and evidencing connections in a collaborative forum. Kumu has been utilised as a visualisation tool due to the range of features offered and the benefits of generating an interactive open-access model (Arena and Li, 2018, McCullough, 2019, Pedersen Zari and Hecht, 2019). This platform enables developed system maps to be made open-access thereby enabling accessibility. This feature facilitates engagement across society thereby supporting justice-led application as well as formulation. Throughout the generation of system maps, graphics and visualisations a combination of colour-blind friendly palettes, symbols and line thickness are used to provide visual clarity.

3.1.2 Validation using expert knowledge

The incorporation of a systems- and justice-led approach requires multidisciplinary perspectives and as such this research has employed focus groups, a questionnaire and semi-structured interviews in order to gain multiple viewpoints and validate the research outputs within practitioners across the sector. Each of these methods has been selected based on the purpose of the validation stage and the individuals engaged.

Focus groups utilise group dynamics to create consensus and build shared understanding from multiple perspectives (UK Government, 2020). As group dynamics support the development of constructive discussion this form of qualitative study benefits from shared experiences within a group, or similar member characteristics which can rapidly form a coherent group dynamic (UK Government, 2020, Kitzinger, 1995). As such a focus group was formed to discuss the premise of the research, i.e. the recognised need to combine environmental and social requirements within visualisations and assessments. The detail of the methodology is provided in Section 3.5

Semi-structured interviews, in contrast enable detailed and specific conversations on an individual basis (Adams, 2015), as such they are particularly suitable where group dynamics may stifle conversations due to the risk of divergence in opinion or perspective between individuals or organisations. The use of a questionnaire may assist to both obtain a broad range of views on specific topics, or to act as a primer for more detailed conversations within either a focus group or semi-structured interview context. Within this research a questionnaire was circulated to invited experts across the water sector to capture a range of perspectives and to ascertain interest in participation in more detailed discussions. For these follow-up discussions semi-structured interview techniques were employed. The detail of the methodology is provided in Section 3.6.4.

3.2 Exploration of relationships across the surface water system using system mapping

M1 – USE EVIDENCE-BASED SYSTEM MAPPING TO EXPLORE RELATIONSHIPS ACROSS THE SURFACE WATER SYSTEM USING A JUSTICE-LED FRAMEWORK. GENERATE THREE PERSPECTIVE-DRIVEN SYSTEM MAPS. FOCUS GROUPS USED FOR VALIDATION.

The development of visualisations was split into two phases (Figure 3-2) and described in the proceeding text.

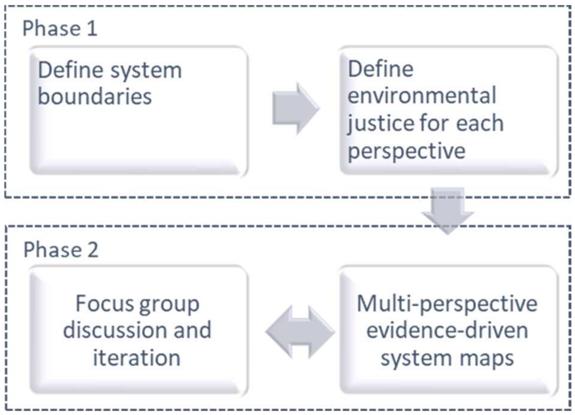


Figure 3-2: Step-wise illustration of method undertaken highlighting the two activity phases

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.

Phase 2: The second phase of research focused on the exploration of relationships within the system using an environmental justice framework. An evidence-based approach was adopted with relationships based on cause-and-effect processes defined through academic and grey literature. A series of focus groups were formed; details of ethical approval for this is included in Appendix A. These focus groups were utilised to discuss and iterate the development of system maps. The transcript of these focus groups is provided in Appendix B and discussed in Sections 4.1 and 5.1). 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 visualisations which can be analysed with integrity.

3.3 Explore the impacts of future scenarios using perspective-driven system maps

M2 – Expand on established future scenarios to consider these at the surface water system scale. Apply these future variabilities and impacts across perspective-driven system maps

Future scenarios have been applied to explore key interactions within a range of potential futures. For the purposes of this research these are four archetypal future scenarios (i.e. Market Forces, Policy Reform, New Sustainability Paradigm and Fortress World) reported by Hunt et al. (2012) and first developed at the global scale by the Global Scenarios Group (Gallopín et al., 1997, Raskin et al., 2002, Raskin, 2004). The justification for incorporating these scenarios is provided in Section 2.5, brief narratives of each are included below:

Market Forces (MF)

This future scenario is characterised 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 behaviours lead to a multitude of impacts including: unchecked user behaviour; 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 behaviours (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 increasing focus on social and environmental policy increases consideration of multi-capitals and the protection of ecosystem services. Technological developments to address sustainability goals are favoured over behavioural 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 demonstrates a transformation and discontinuity from the historic trajectory. 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, organisation and unsustainable practices (Gallopín et al., 1997, Hunt et al., 2012).

New Sustainability Paradigm (NSP)

The final future scenario, this represents a 'great transition' away from historic trajectories which occurred following widespread concern and evidence of large-scale planetary shifts. Humane globalisation drives a values-led change to simplicity, tranquillity 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 behaviours and the adoption of material sufficiency as a preferred lifestyle (Gallopín et al., 1997, Hunt et al., 2012).

These scenarios have been expanded using a society-technology-environment-economy-policy (STEEP) drivers' framework to ascertain how they would manifest at the UK surface water system scale. The aim of analysis within this structure is to examine the external factors that impact the system. There are various stratifications of these characterisations that can be used depending of the level of details required and the nature of the entity under examination. The differentiation between frameworks comes from sub-categorisation of attributes such as STEEPO (society-technology-environment-economy-policy-organisation) which incorporates organisational drivers, PESTLE (political-economic-societal-technological-legal-environmental) considering legal separately and STEEPLE (societal-technological-environmental-economic-political-legal-ethical) also considering ethical separately. This reflects a requirement for some entities to pay particular attention to the legal and ethical attributes of a business or decision. In the case of futures analysis of water systems it is considered that legal and ethical considerations can reasonably be incorporated into the political and societal drivers, therefore a STEEP analysis has been conducted.

3.4 Identification of key points of interaction

M3 – Analysis of perspective-driven system maps (including future scenarios) to define key points of interaction across perspectives and future scenarios

Analysis and comparison of system maps (Objective 2, Method 2) to illustrate pathways to impacts across future scenarios identified key points of interaction. Within each future scenario the key impacts were identified, the pathways leading to these impacts were analysed and the driving forces operating therein identified.

3.5 Development of conceptual model

M4 – Develop casual loop diagram centred on the key points of interaction

The identified key points of interaction formed the basis of the development of a causal loop diagram which can act as a conceptual model of the defined water system 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 research processes and outputs has been facilitated through formation and engagement with a focus group. Ethical approval was obtained for the purposes of forming and utilising the focus group, this is provided in Appendix A. This focus group consists of six individuals located across Sweden, UK, USA and Canada who all have an interest in systems approaches and sustainability and social justice. Participants have combined experience across water and wastewater treatment, smart water, smart cities, innovation, disaster relief, political science, computing, economics, industrial engineering, organisational psychology and environmental stewardship. The focus group members were approached individually through a collaborative forum, Pivot Projects[19] (http://www.pivotprojects.org), of which they are a part. A diversity in experiences, specialities and geography has provided rigorous discussion of the research outputs. 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 (Appendix B).

3.6 Indicators to support an environmental justice-led approach

M5 – Literature analysis driven by key points of interaction used to review existing indictors and define indicators to represent holistic concerns

The assessment, and identification, of indicators to reflect a goal of environmental justice in water systems was carried out in a process as described in Figure 3-3.

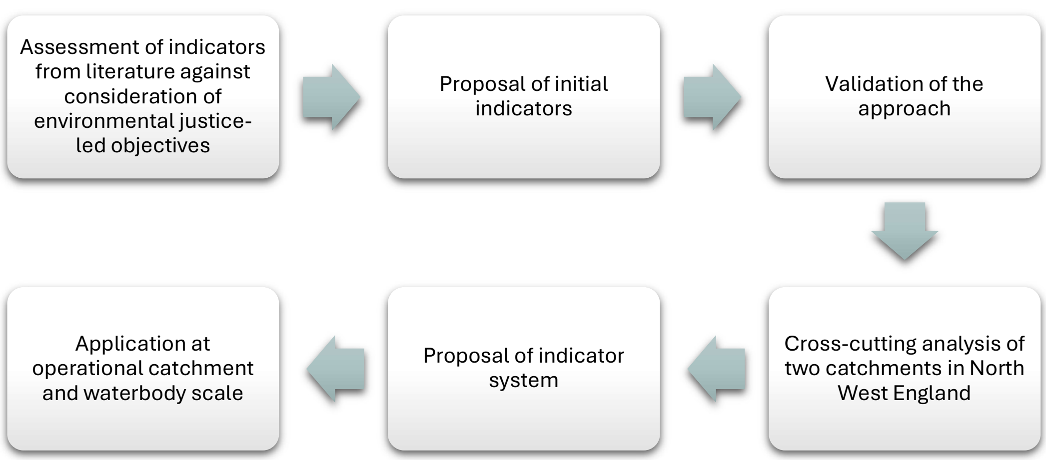


Figure 3-3: Flow diagram of six-stage process for indicator assessment and identification

[19] Pivot Projects is a voluntary collaboration established in 2020 which seeks to explore ecological challenges through holistic approaches and the identification of methods to enable transformational change.

3.6.1 Assessment of indicators from literature

3.6.1.1 Identification of indicators within the literature

The literature has been assessed (Figure 3-4) to compile a summary of the indicators currently proposed and used globally in assessments of water systems. Literature databases were searched using the terms 'sustainable development' AND (measurement OR benchmark OR index OR indicator) AND water AND society. This yielded 570 results which were refined using the method specified in Figure 3-4. The exclusion of results containing the term 'water resources' in title-abstract-keywords was used to remove those assessments which had water resource management as a main purpose. A randomised examination of a subsection of the excluded results supported their removal as the indicators reported therein were restricted to those considering water as a resource and the economic implications of this. These indicators were also present in the remaining literature therefore the exclusions were not considered to greatly impact the overall range of indicators assessed. Further refinement through a review of abstracts and the removal of duplicates reduced the analysis to 40 results. To these search results grey literature was added along with known, relevant academic literature which was not present in the search results. This led to a total of 60 sources of indicators included in the assessment.

Indicators presented within the selected literature were extracted yielding a long list of 713 indicators which were subsequently organised into broad categories under the headings of environment, society and economy. Within each of these categories the indicators were assessed for duplication, relevance to the assessment of environmental justice within the surface water system and availability of data required to support the indicator.

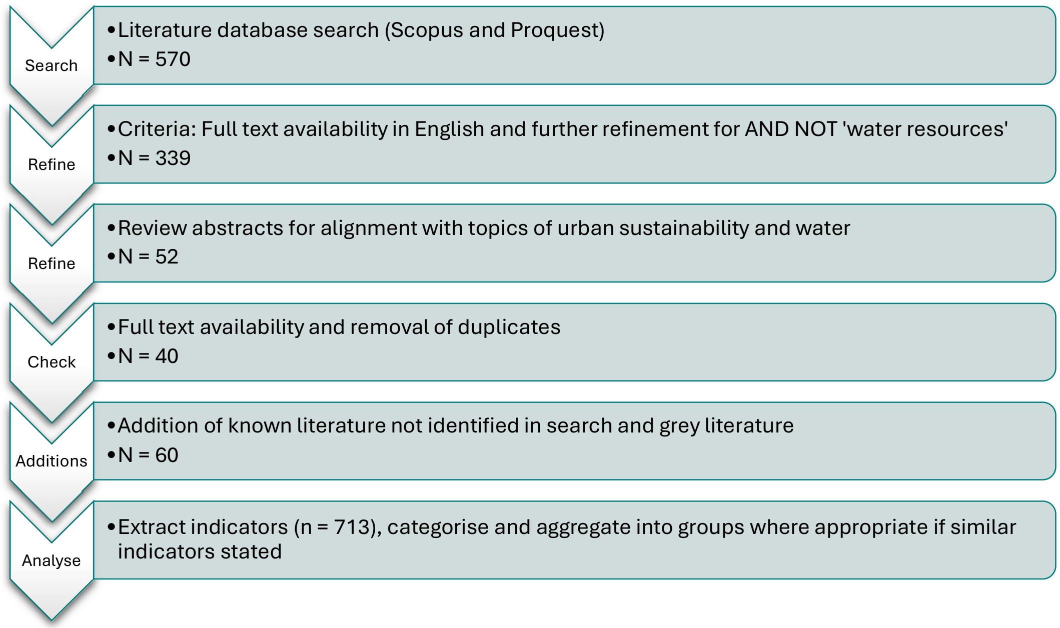


Figure 3-4: Flow diagram of literature review process for assessment of indicators within literature.

3.6.1.2 Comparison against consideration of environmental justice-led objectives

The use of indicators implies a standard to which comparisons are made either as a benchmark to strive towards or a threshold to avoid dipping below. Within this study 'success' for ecological and societal users of a surface water system are the conditions that are needed to thrive under a definition of environmental justice. In contrast, environmental justice from an economic perspective differs in that the economy can be viewed as the theories and mechanisms that describe our interactions within society and the wider world. With this in mind the objective of environmental justice from this perspective changes from creating an ability to thrive into a mechanism to enable equitable, functioning societal and environmental systems to perpetuate. This would provide prosperity across the nation, and affordable, equitable funding of water services – both currently and which can be sustained into the future. The relationships underpinning the ability of a system to thrive under these definitions has been explored using systems mapping and causal loop diagrams in (Bowman et al., 2024) and summarised in Figure 3-5.

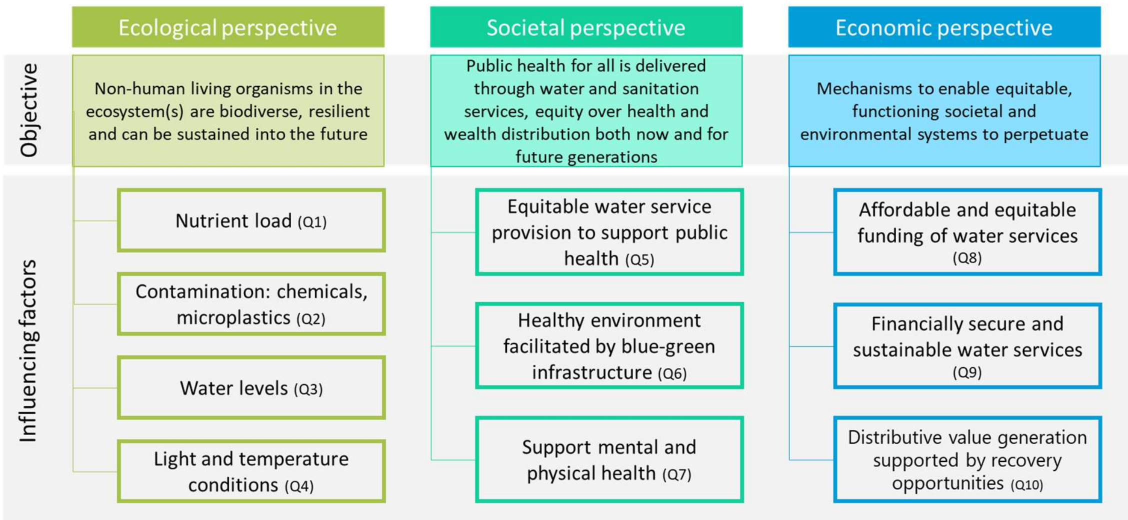


Figure 3-5:Environmental justice from ecological, societal and economic perspectives and the factors influencing these objectives

Based on the influencing factors detailed in Figure 3-5 a series of ten questions were posed to assess whether existing indicators enabled consideration of environmental justice-led objectives across each perspective. This process structured the critique of existing indicators around a consistent framework using the following questions as prompts:

Questions reflecting an ecological perspective:

Q1. Does the nutrient load entering the surface water system negatively impact the ecosystem?

Q2. Are contaminants in the form of chemicals and plastics, including microplastics, present in quantities that negatively impact the ecosystem?

Q3. Is flow sufficient to maintain life and support the ecosystem throughout the year?

Q4. Does anthropogenic modification of the surface water system, and surrounding environment, impact light levels or temperature to the extent that they negatively impact the ecosystem?

Questions reflecting a societal perspective:

Q5. Are water and sanitation services provided equitably across the population in support of public health?

Q6. Is a healthy environment available through equitable implementation of blue-green infrastructure?

Q7. Does the surface water system contribute to local mental and physical well-being?

Questions reflecting an economic perspective:

Q8. Does the cost of water and sanitation services impact the population equitably?

Q9. Is the provision of water and sanitation services financially secure and sustainable?

Q10. Are value generation opportunities across water and wastewater services optimised across the surface water system?

3.6.2 Proposal of indicators: initial view

This process provided an assessment of the incorporation of environmental justice-led objectives within existing indicators. This allowed the identification of aspects which were absent enabling the generation of an initial view of potential indicators, and methods of application which could be validated against expert knowledge prior to full development of an indicator system and example application.

3.6.3 Validation: testing against expert knowledge and availability of data

The proposed methods and indicators were validated through the use of a questionnaire and semi-structured interviews which surveyed opinions from experts across the water sector in England (Figure 3-6). Ethical approval was obtained for the completion of the questionnaire and semi-structures interviews, the details of which are included in Appendix C.

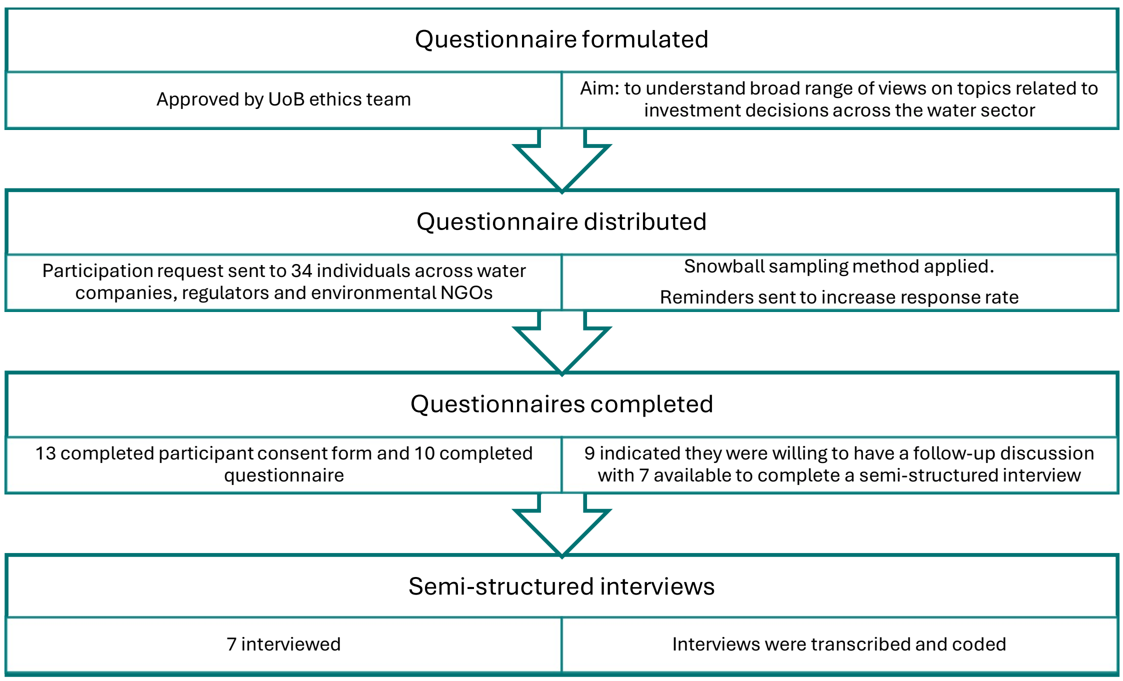


Figure 3-6: Method applied for validation using questionnaire and semi-structured interviews

Invitations to participate were circulated amongst experts known to the author and snowball sampling methods were applied to increase the distribution and ensure representation from across the water sector. The request was sent to a total of 34 individuals with periodic reminders sent, responses were received from the questionnaire from 10 participants (full results are presented in Appendix D and analysed in Section 4.4.3) and follow-up discussions were arranged with seven of these participants (transcripts are provided in Appendix E and analysed in Section 4.4.3). Demographic information was recorded as part of the questionnaire to determine if there was an age, gender or ethnicity bias to the participant group which may impact the responses. The respondents were spread across water companies, regulators, government agencies, non-governmental organisations (NGOs) and consultants which advise both water companies and government. Additionally, participants in the semi-structured interviews represented this full range of organisations, therefore it can be concluded that the results of the validation are representative of cross-sectoral views. The respondents included a mixture of male and female individuals as well as multiple ethnicities. Whilst the small number of respondents limits representation, as does the bias within the sector, the respondents were not a homogenous demographic and provided a range of backgrounds and viewpoints.

The small number of responses (10 out of 34 – 30%) was not unexpected due to the targeting of validation to utilise experts in the field. Whilst this limits the ability to utilise statistical interpretation of the results[20], overarching views could be understood; moreover the use of free-text boxes enabled elaboration from respondents. Furthermore, the questionnaire acted as a primer for in-depth discussions in which 90% of respondents were willing to participate. The transcripts from these discussions were recorded, anonymised and coded to align approximately with the sections of the questionnaire: premise of the research; representation

[20] The purpose of the questionnaires was not to make statistical inferences across all people within England and Wales that would have an informed view on this topic, instead the objective was to act as a primer for more in-depth discussions. Although it is commonly accepted that a sample size over 30 enables statistical analysis this is subject to the understanding of variance within the population. In this case the variance within the population is unknown and expected to be considerable due to the range of experiences and priorities, therefore a more in-depth assessment of sample size requirement has been undertaken. Calculated based on providing 95% confidence of representation of views within a relevant water sector population of 7,500 and including a 5% margin of error, would lead to a sample size of 366 individuals if statistical inference had been the objective. Assuming an optimistic response rate of between 5% and 10% this would require surveys being sent to between 3,660 and 7,320 individuals. Data collection on this scale was not considered achievable within the constraints of this study and was not critical to the interpretation of the questionnaire and semi-structured interview responses.

of views from environmental, social and economic perspectives; translation into action plans; future planning; priorities, views and the role of trust; visualisation methods and requirements; future impacts.

3.6.4 Cross-cutting analysis of two catchments in North West England

Exploratory analysis of two inland surface water systems (Figure 3-7) with considerably different characteristics (Table 3-2) was undertaken to understand data availability, the scale at which it was available and the information that could be inferred from this[21].

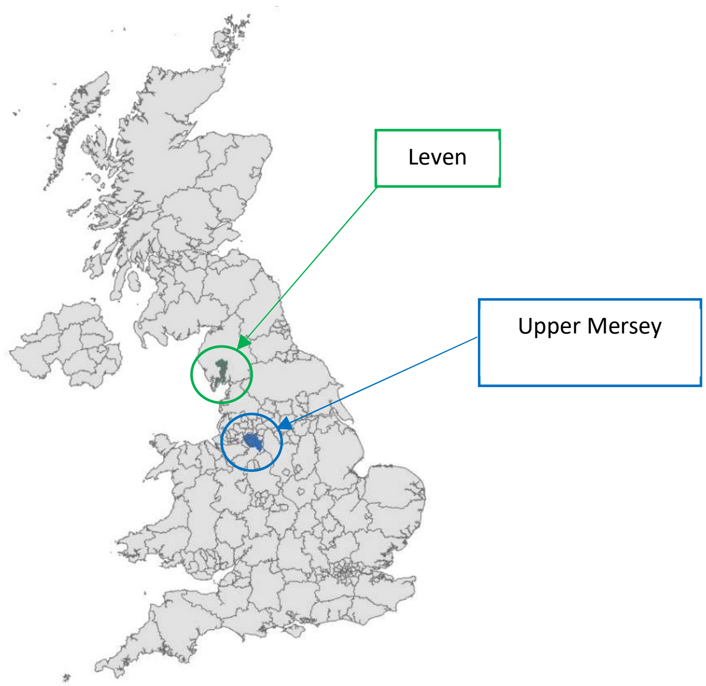


Figure 3-7: Map of the UK showing the location of the Leven (green) and Upper Mersey (Bollin and Dean) (blue)

[21] These catchments were selected due to the variation in characteristics provided by each and author familiarity with the catchments, this knowledge was deemed necessary as it was considered a participatory application of the tools within a case study was unlikely due to political and reputational pressures at the time across relevant stakeholders.

Table 3-2: Characteristics of selected catchments

Characteristic	River Leven	Upper Mersey (Bollin and Dean)
Total length*	171km	295km
Waterbodies within the operational catchment*	14 rivers and 11 lakes of which 0 rivers and 5 lakes are heavily modified	21 rivers and 12 lakes of which 11 rivers and 11 lakes are heavily modified
Precipitation**	2,241mm per year 2024 data – Tower Wood Mean: 6.06mm per day Maximum: 94.57mm per day	1,118mm per year 2024 data – Carrington Lane Mean: 3.06mm per day Maximum: 66.39mm per day
River level range**	0.33m to 0.73m 2024 data range at Newby Fish Sluice. Point at southern end of Windermere	0.325m to 4.153m 2024 data range at Ashton Weir Point near confluence with Manchester Ship Canal
River flow**	Mean: 17.56m^3 per day Range: 2.03 – 61.18m^3 per day 2024 data – Newby Bridge. Point at southern end of Windermere	Mean: 16.89m^3 per day Range: 4.35-212.35m^3 per day 2024 data – Ashton Weir Point near confluence with Manchester Ship Canal
Conurbations	Predominantly rural location with substantial livestock farming and small towns and villages	Headwaters are predominantly rural although catchment incorporates urban areas including Macclesfield, Stockport and south Manchester.

** Data from Environment Agency Catchment Data Explorer (https://environment.data.gov.uk/catchment-planning)*
*** Data from Defra Hydrology Data Explorer (https://environment.data.gov.uk/hydrology/landing)*

Leven

This catchment is situated in South Cumbria in North West England. It incorporates Windermere, is part of the Lake District National Park and as such is a UNESCO world heritage site (UNESCO World Heritage Convention, 2023). It also includes the towns of Bowness-on-Windermere, Windermere (town) and Ambleside which are popular tourist destinations. The river catchment consists of a number of tributaries, rivers and lakes that traverse through agricultural land and built-up areas before converging in Windermere and continuing on to the coast at the north end of Morecambe Bay.

Upper Mersey (Bollin and Dean)

The branch of the Upper Mersey that includes the rivers Bollin and Dean. It is situated in North West England and stretches from the edge of the Peak District through urban areas of Stockport and Manchester before merging with the Manchester Ship Canal and forming the Lower Mersey which flows east to west from Manchester to Liverpool where it opens into the Irish Sea. The Upper Mersey (Bollin and Dean) area traverses agricultural, woodland and urban areas with a strong industrial heritage.

3.6.5 Proposal of indicators at the surface water system scale

The factors influencing the objectives of environmental justice (Figure 3-5) were used as the basis for the definition of indicators for each perspective. The availability of data sources at an appropriate level of granularity and reliability was used to refine the definition of indicators. In addition to the definition of the indicator itself, performance bandings of inadequate, satisfactory and target were defined to enable benchmarking of relative performance across indicators.

Due to known issues with the availability of environmental data, and the substantial benefits to the inclusion of local knowledge into assessments a further 'healthcheck' stage has been added. This prompts and stimulates the assimilation of local knowledge with formal data sources to provide an assessment which is accepted within stakeholders as representative. This is proposed in contrast to the use of weightings that prioritise certain indicators over others. Whilst a weightings-based approach is prevalent within the literature (Abedin and Shaw, 2014, Chen et al., 2022, Gain et al., 2016, Hu and Han, 2023, Li and Li, 2019, Liu et al., 2020, Mao et al., 2020, Mishchuk et al., 2019, Raya-Tapia et al., 2022, She et al., 2022, Sun et al., 2022) herein it is not considered consistent with a justice-led approach. The application of weightings has the potential to introduce bias since the result is reflective of those individuals involved in the provision of weightings. As the focus of these proposed indicators is a justice-led approach, ensuring that the full breadth of users of the water environment are reflected in the assessment is critical.

3.6.6 Application at operational catchment and waterbody scale

Returning to the Leven and Upper Mersey (Bollin and Dean) operational catchments, the proposed indicators are applied, and visual outputs generated, to illustrate how the assessment could be implemented. Further to this, the application of indicators is extended to the waterbody scale, using the Upper Mersey (upstream of MSC) as an example waterbody. This has the advantage of being a large waterbody that encompasses several Lower Super Output Areas (LSOAs) enabling thorough analysis of this waterbody as a system.

3.7 Application at different tiers of practice

M6 – Application at different tiers of practice

The tools which have been developed have been applied to potential interventions. The first of these considers the introduction of a governance mechanism around water pricing, whilst the second introduces a technological innovation into the water system. These examples have been examined as they encompass the inter-related concepts of social norms, value and technology.

3.7.1 Governance mechanism: Water pricing measures

The impact of water pricing mechanisms and the role of water price as a mechanism by which to increase the value that society ascribes to water, leading to improved environmental and social outcomes. This research was completed by a collaboration between members of Pivot Projects[22] leading to the development of a series of interconnected governance mechanisms to enable justice-led water pricing as a trigger to enable sustainable water use[23].

The combination of these proposed pricing mechanisms has been tested using the tools generated through this research. This assessment has considered how the proposed mechanisms interact with assessment indicators and potential risk areas when considering application within alternative future scenarios.

The outcomes of this assessment are discussed to understand how this may enable the development of governance processes that enable environmental-justice-led outcomes and are responsive to externalities in such a way that outcomes are preserved.

3.7.2 Technological innovation: Pipebots

Technological innovation is an integral part of the water sector improving service provision and efficiency as a response to externalities. Many technological innovations are under consideration by the sector, as such tools to enable analysis of long-term impacts would enable the mitigation of risk in technology adoption. One such technological innovation is Pipebots, a current EPSRC research grant (Grant number EP/S016813: Pervasive Sensing of Buried Pipes) which aims to progress towards pervasive, autonomous robots providing inspection of buried pipe infrastructure. The objective to enable greater network coverage and proactive

[22] Introduced fully on page 90. Pivot Projects is a voluntary collaboration established in 2020 which seeks to explore the world's ecological challenges through holistic approaches and the identification of methods to enable transformational change.

[23] The outputs of this research is published as: The water pivot: Transforming unsustainable consumption to valuing water as a resource for life BOWMAN, B. M., ABBOTT-DONNELLY, I., BARSOUM, J.-F., WILLIAMS, P., HUNT, D. V. L. & ROGERS, C. D. F. 2023. The water pivot: transforming unsustainable consumption to valuing water as a resource for life. *Frontiers in Sustainability,* 4..

management of buried pipes is predicted to reduce disruption to communities and enable improvements in service delivery. Consideration of the business model and case for change throughout the early stages of research and development is being undertaken to decrease risks associated with implementation and adoption.

Developing a new technology requires consideration of the range of conditions it will operate under, whilst physical conditions are typically considered during development, the wider context within which the technology will operate is also important. For implementation of the technology in the long-term to be successful, varying conditions and changing socio-economic priorities should be considered in the alignment with regulatory requirements as well as the development of implementation strategies and business models. This assessment considers the potential impacts of the technology within the water system from multiple perspectives, interaction of the technology with proposed indicators and risks to ongoing adoption of the technology across alternative future scenarios. The outcomes of this assessment are examined to generate insights which can be used in the development of Pipebots as a technology for implementation.

4 RESULTS

The results of objectives 1 to 5 are presented within this chapter (Table 4-1). System mapping has been used to identify key relationships in the surface water system from the perspectives of the economy, society and the environment. This has been carried out using an environmental justice lens to explore the relationships which enable the system to thrive and support equitable distribution of benefits and dis-benefits. Analysis has revealed key relationships and the external factors that drive changes through the system such as governance mechanisms, infrastructure, societal priorities and climate impacts (Section 4.1). The key interfaces and leverage points became more apparent when future scenarios were applied; the effects of different socio-economic scenarios, explored at the system scale, were demonstrated through visualisations to illustrate how the relationships would be strengthened or weakened within future scenarios (Section 4.2). Extreme scenarios, applied at the system scale demonstrate the relevance of approaches to product generation, treatment capacity and capability, cost recovery and urban development to the impacts occurring within the surface water system (Section 4.3).

These assessments enable understanding of the conditions under which a proposed intervention or action will operate in as well as developing understanding of current requirements and how these relate to future needs. To increase the value and application of assessments it is beneficial to have the ability to provide comparisons using common criteria. The environmental justice-led approach fundamental to the development of system maps, and the key points of interaction on indicator systems have been proposed to enable such assessments. These indicators have been applied at the operational catchment and waterbody scale (Section 4.4).

Table 4-1: Summary of chapter section, objective and the associated method. Outputs from Objective 6 are presented and discussed in Chapter 5

Results Section	Objective	Method
4.1	O1 – Explore relationships across the surface water system using a justice-led framework	M1 – Use evidence-based system mapping to explore relationships across the surface water system using a justice-led framework. Generate three perspective-driven system maps. Focus groups used for validation
4.2	O2 – Explore these relationships using future scenarios	M2 – Expand on established future scenarios to consider these at the surface water system scale. Apply these future variabilities and impacts across perspective-driven system maps
4.3	O3 – Define key points of interaction across perspectives and future scenarios O4 – Refine the exploration of key points of interaction within perspective-driven system maps and across future scenarios into a causal loop diagram of the surface water system centred on the key points of interaction	M3 – Analysis of perspective-driven system maps (including future scenarios) to define key points of interaction across perspectives and future scenarios M4 – Develop casual loop diagram centred on the key points of interaction
4.4	O5 – Define indicators to represent holistic concerns across the surface water system and reflect the key points of interaction	M5 – Literature analysis driven by key points of interaction used to review existing indictors and define indicators to represent holistic concerns

4.1 Visualising relationships within the surface water system

4.1.1 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 summarised in Figure 4-1) 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. A place-based approach has been adopted with the system defined as surface waters extending from headwaters to transitional areas, including lakes and wetlands. This incorporates utilisation and consumption activities as indicated by red text within Figure 4-1.

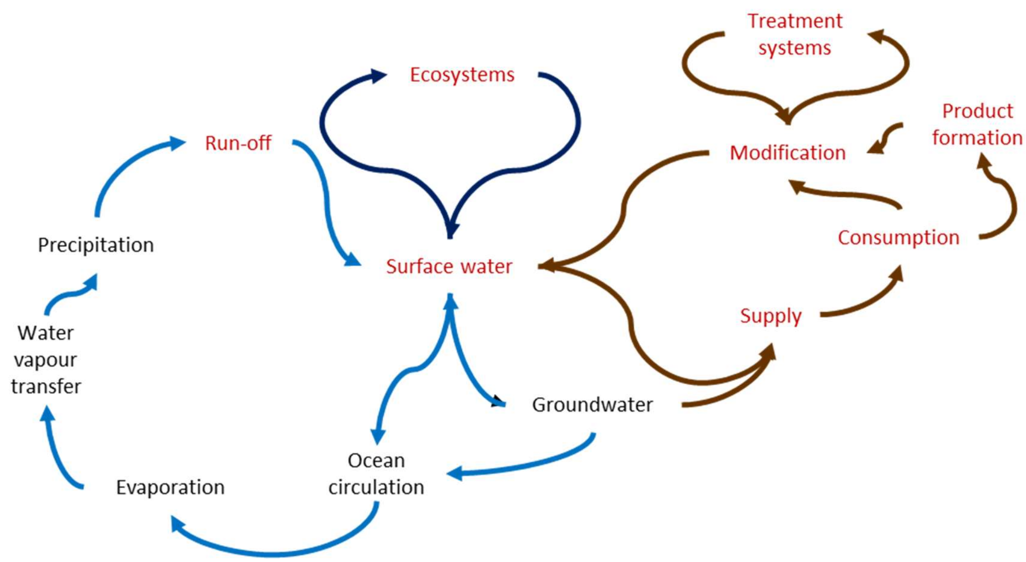


Figure 4-1: Water system. Light blue arrows represent hydrologic cycle, dark blue arrows represent interactions with ecosystems and brown arrows indicate impacts of anthropogenic activity on water systems. Red text highlights the system of interest within this study.

As discussed in Chapter 2, 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, as discussed in Section 2.2, is explored. In general, environmental justice has been coined as a term to represent a specific form of justice in which social and environmental equity are prioritised (Agyeman and Evans, 2004, 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.

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 summarised 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. This generates an environmental justice-led framing for the examination and characterisation of relationships within system maps and could be further developed into more specific, targeted definitions specific to local context and conditions in the development of location-specific system maps.

The incorporation of social justice within system mapping was supported by a focus group used to validate the approach. The prevalence of social justice issues across their combined experience, was evidenced in the focus group workshop[24] as illustrated in the 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."*

"it was social equity, or lack thereof, that led to the situation that exists in the first place. Populations are unequal because they're unequal. They have a hard time arguing for equality and winning that argument."

4.1.2 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 visualisations as a means to provoke change, for example it was stated that:

[24] Transcript of these discussions is presented in Appendix B

"In science all the major breakthroughs are when you get the telescope, the microscope, the MRI scan etc that do visualisations and you can see information in ways you've never seen before."

"By visualizing 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 can't visualize what's going on."

…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"*

System maps were developed in this research for each of the ecological, social and economic perspectives (Figures 4.2 – 4.4 respectively), these branch through cause-and-effect relationships from the central, environmental justice aspiration. The branches contain linked activities, policies and characteristics; however, to make them legible cross-connections have been excluded from the system maps[25]. Pathways that would be considered supportive (shown as solid lines) are those that are enablers, whilst pathways that are potentially destructive (dashed lines) limit the ability to thrive. For example, within the societal perspective water and sanitation infrastructure that enables public health to be ensured across society equitably (Assmuth et al., 2017, Dushkova et al., 2021, Mashhoodi, 2021). Conversely, extreme rainfall

[25] The inclusion of connections which link different branches, such as excess nutrients (nutrient branch) and eutrophication (temperature and light branch), although correct would lead to additional complexity within the system maps obscuring the information that can be interpreted from them. As such these connections have been excluded from the diagrams.

events, whose frequency is exacerbated by climate change (IPCC, 2021) and urbanisation 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). The depiction of these networks of relationships illustrates the influences that shift the balance of the system to be either supportive or destructive towards the objective of environmental justice. Appendix F provides an exploration of the system maps with accompanying explanatory narrative and Table 4-2 provides an explanation of the legend used across the system maps.

Table 4-2: System map legend - explanation of terms

Grouping	Depiction	Explanation
Node: Users	Blue circle with image of people	A user of the system or the environment that a user creates for the system
Node: Feature	Purple circle with image of flask	An attribute of the system that changes the experience of users
Node: Resource	Pink circle with image of cogs	Resource (presence or absence) that could be utilised by users
Node: Control	Yellow circle with image of pillared building	Mechanism of control over the system (such as treatment, regulation etc.)
Connection: Flow of water	Wide dark blue arrow	Movement of water between nodes
Connection: Flow of nutrients or products	Wide green arrow	Movement of nutrients or products between nodes
Connection: Flow of contamination	Wide orange arrow	Movement of contamination between nodes
Connection: Impact of infrastructure or human users	Narrow bright blue arrow	Direction of impact of infrastructure or human users between nodes
Connection: Influence of control mechanisms	Narrow purple arrow	Direction of influence of a control mechanism within the system
Connection: Transfer of money	Narrow teal arrow	Direction of movement of money within the system and connection to the nodes this influences

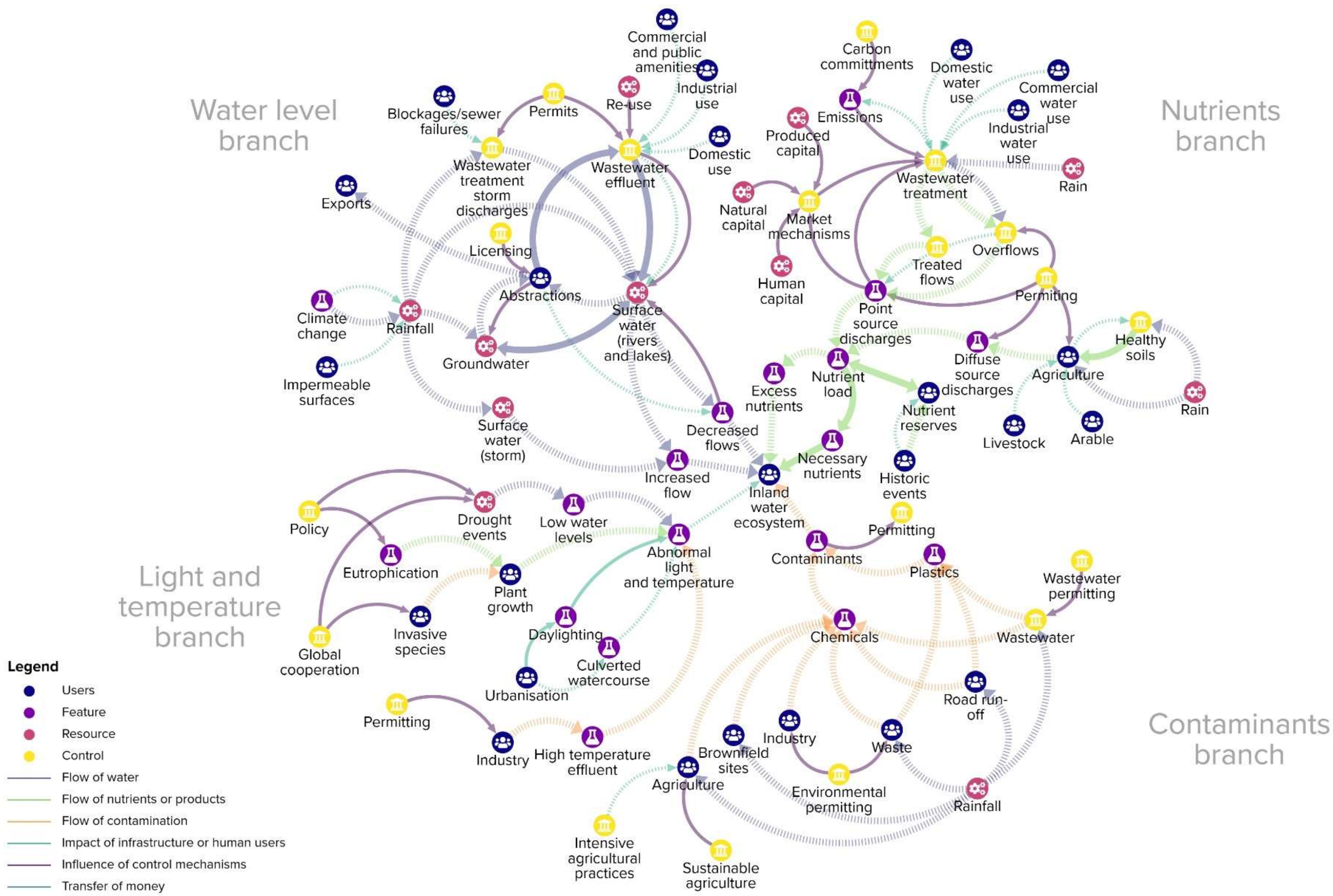


Figure 4-2: Ecological perspective system map with supportive relationships depicted as solid lines, and destructive relationships shown as dashed lines.

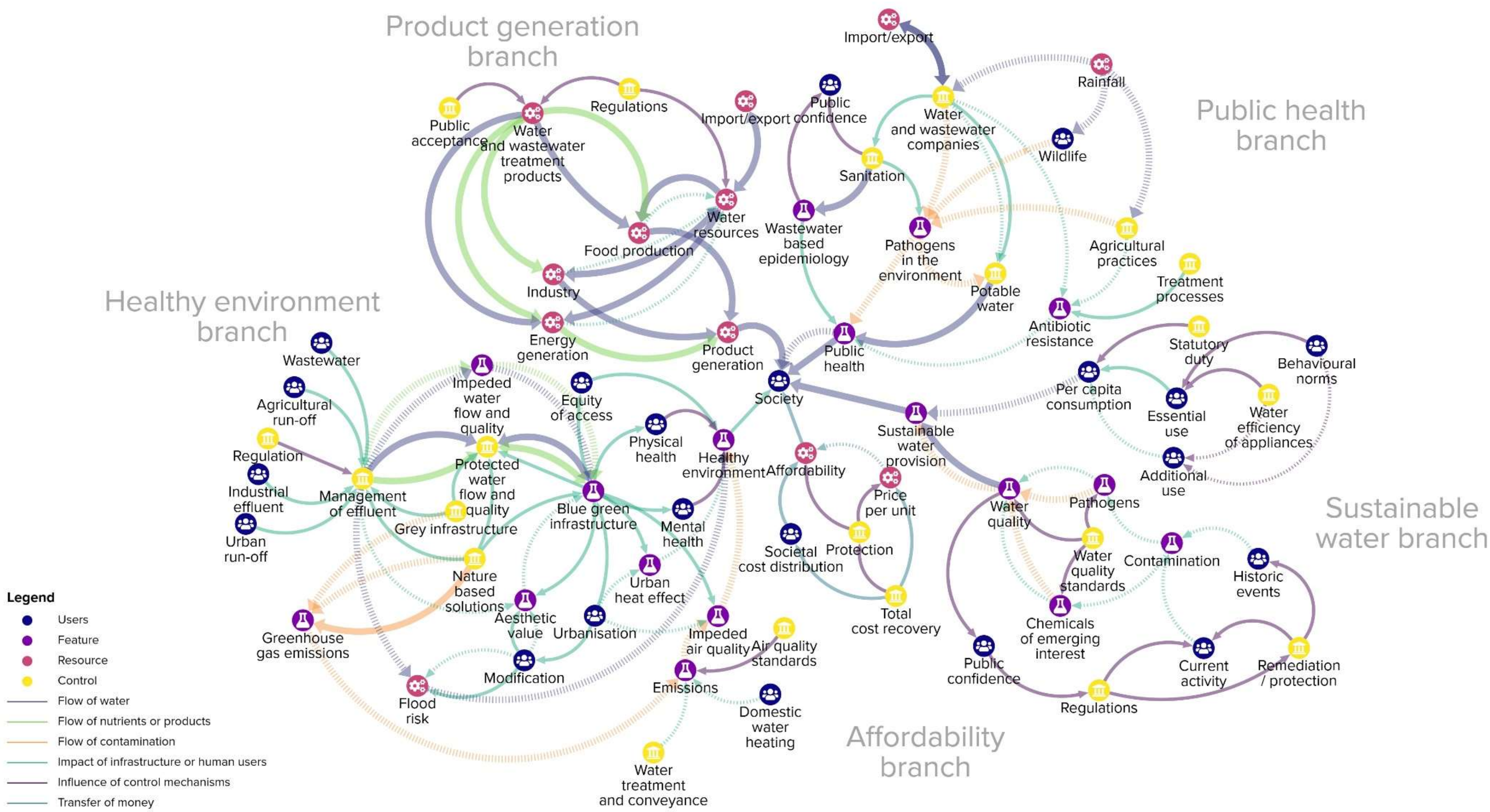


Figure 4-3: Societal perspective system map with supportive relationships depicted as solid lines, and destructive relationships shown as dashed lines.

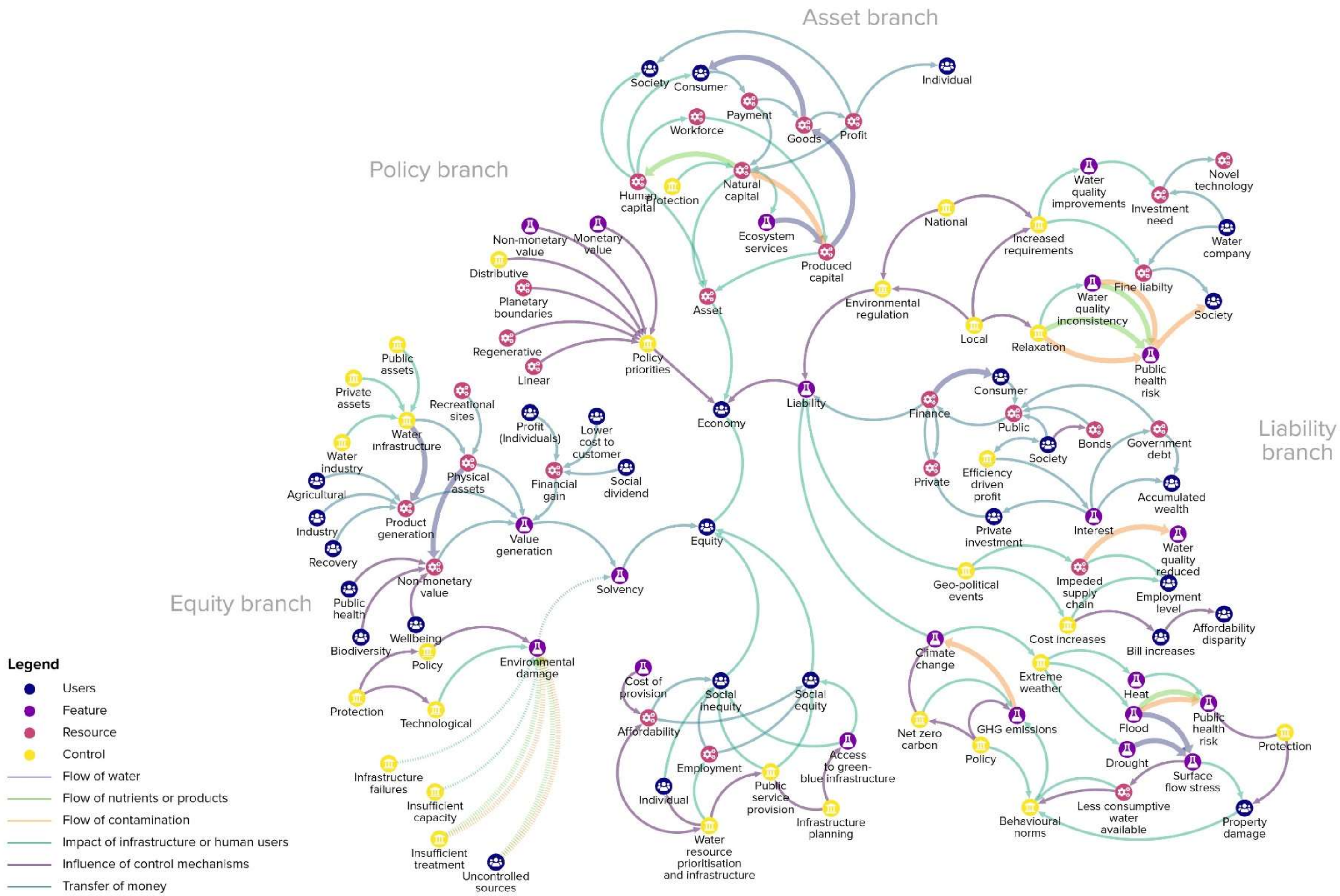


Figure 4-4: Economic perspective system map with supportive relationships depicted as solid lines, and destructive relationships shown as dashed lines

4.2 Expanding understanding through the use of future scenarios

The effect on these three perspectives is further explored through the application of the four archetype future scenarios outlined in Section 3.3

The scenarios offer a description of potential futures at a global scale, and it is noted in Gallopín et al. (1997) that these should be developed and considered at the regional, country and local scales in order to be of greatest value. In the following sections each of the selected future scenarios will be considered first, briefly, at the global level, then in more detail at the surface water catchment level. These are accompanied by diagrams (Figures 4-5, 4-9, 4-13 and 4-17) which relate global characteristics within each scenario with impacts for UK inland surface water systems under the perspectives of the environment, society and economy. These characteristics are illustrated by variations in importance of relationships within system maps (Figures 4-6 to 4-8, 4-10 to 4-12, 4-14 to 4-16 and 4-18 to 4-20).

4.2.1 Market forces (MF)

The global scale

A future in which competitive markets are used to balance the opposing sides of environmentalism and growth in both population and the economy. A global population increase is accompanied by a growing income gap both within and between countries. Although there is a greater focus on rights, this is accompanied by a weakening of global governance and welfare policies leading to greater social inequity. Economic growth, defined in terms of increasing GDP, is prioritised although the per capita consumption of raw materials and energy has plateaued in line with the net zero agenda. A focus on competitive markets as a means of balancing needs leads to the decentralisation of authority and the growing strength of the global private sector (Gallopín et al., 1997, Hunt et al., 2012).

Technological advances to enable more efficient use of resources and the transition to Industry 4.0 are tempered by free market behaviour. There is global deterioration of the environment, increasing use of resources in pursuit of goods generation leading to a rate of resource depletion that is in excess of renewal. Urbanisation leads to a concentration of people, industry and therefore pollutants as well as a dissociation of people and planet. Environmental improvements in rich planetary regions are limited by the pursuit of economic growth (Gallopín et al., 1997, Hunt et al., 2012).

There is a slight increase in political pressures and conflict; resource depletion, especially concerning fossil fuels has led to geo-political instability. Additionally, migration pressure exacerbated by climate change impacts and political instability increases. Conflict resolution is focused on the preservation of the prerogatives of the powerful (Gallopín et al., 1997, Hunt et al., 2012).

At the inland surface water system scale

Focussing on the impacts a MF world would have on the inland surface water system provides a context-specific view of how relationships may change (Figure 4-5). Increasing inequity leads to spatial disparity in the quality of the surface water environment, localised degradation and the differences in ability for society to access blue-green infrastructure. Increasing emphasis on 'Big data' channels water industry investment to areas of greatest need albeit with a narrow focus, however, the prioritisation of economic growth leads to short-termism of investment coupled with a focus on 'least cost'.

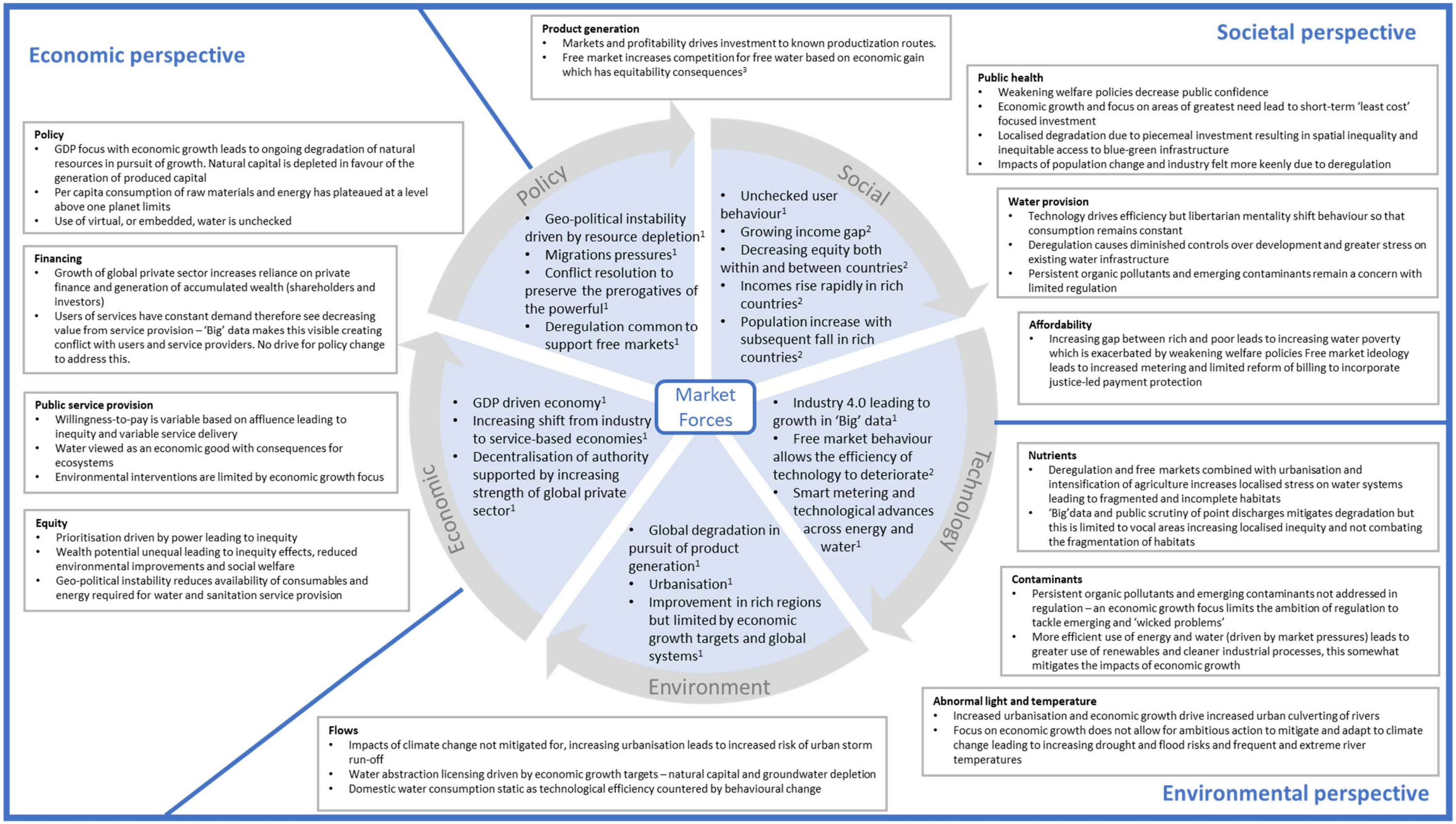


Figure 4-5: Translation of global trends in MF future scenario to the UK surface water system scale (In image references 1 - Gallopín et al. (1997) , 2- Hunt et al. (2012), 3 -Bowman et al. (2023)

Deregulation leads to greater stress on existing water industry assets as controls over development are diminished, therefore the impacts of population and trade effluent changes are felt more keenly. Per capita consumption of water overall remains static as technological developments drive greater water efficiency of technology which is countered by behavioural shifts driven by a free-market mentality. Urbanisation and intensification of agriculture leads to greater localised stresses, with deregulation reducing permitting as a control mechanism. 'Big data' and public scrutiny of point discharges leads to some mitigation through public demands.

The impacts of climate change are seen to increase as a market-driven philosophy does not lead to wholesale reductions in emissions, in the UK this results in increased severity and frequency of extreme rainfall and increased incidence of drought events as weather patterns become more extreme. Surface water and wastewater storm flows increase leading to increased likelihood of faecal contamination entering the surface water system. The impacts of deregulation, investment driven by the agenda of the powerful and decentralisation of authority increases inequity in access to blue-green infrastructure.

MF influences on relationships across the perspectives of environment, society and economy

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 (Figure 4-6). 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. Geo-political events and climate change impact the provision of services through capability and cost. This is exacerbated by localised interpretation of environmental regulation resulting in inconsistency in both water quality and public health (Figure 4-7). 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 (Figure 4-8) regulation and existing infrastructure standards provide a framework, however this is undermined by behavioural trends characterised by individualism 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.

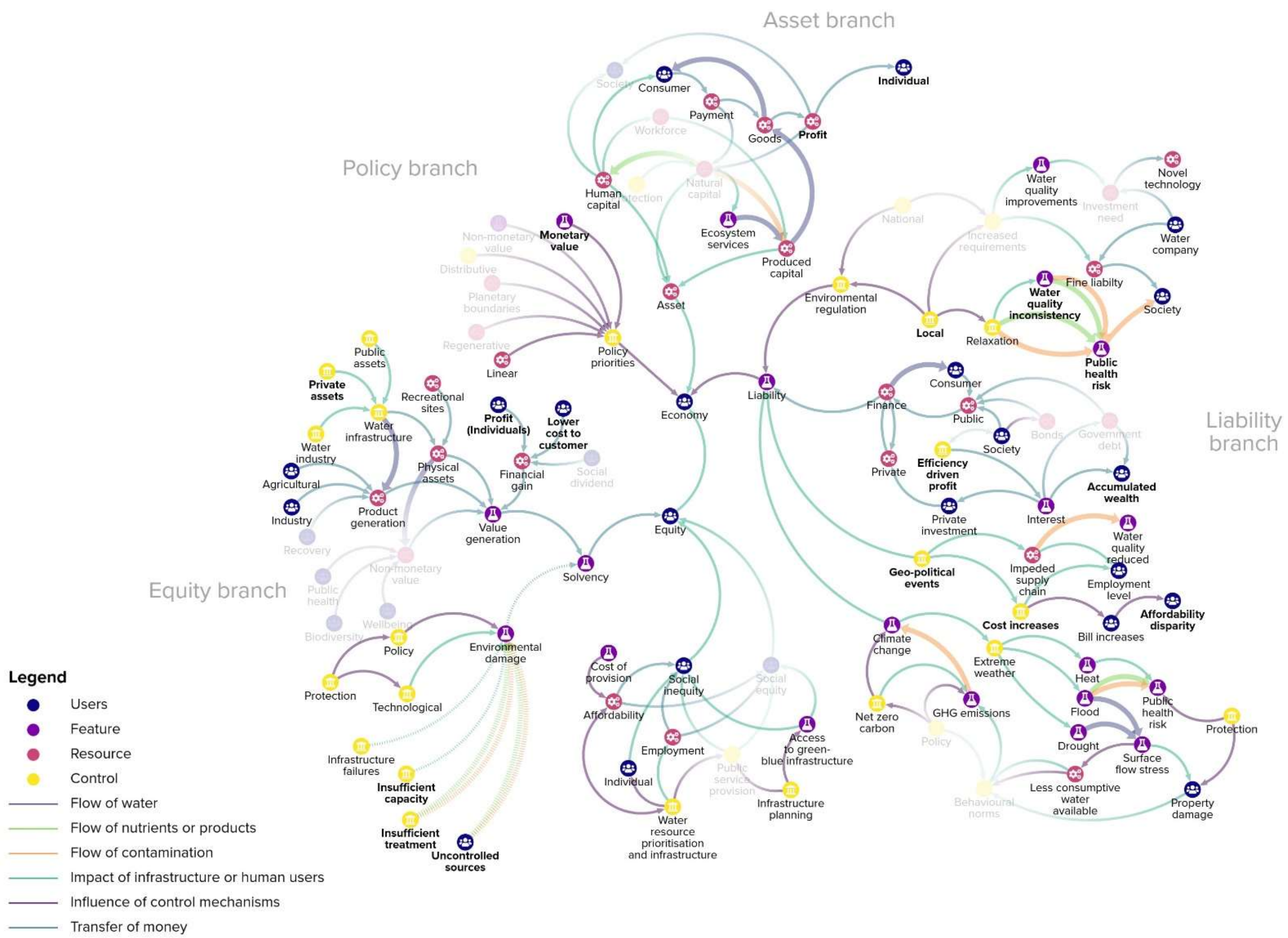


Figure 4-6: Economic perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a MF future scenario

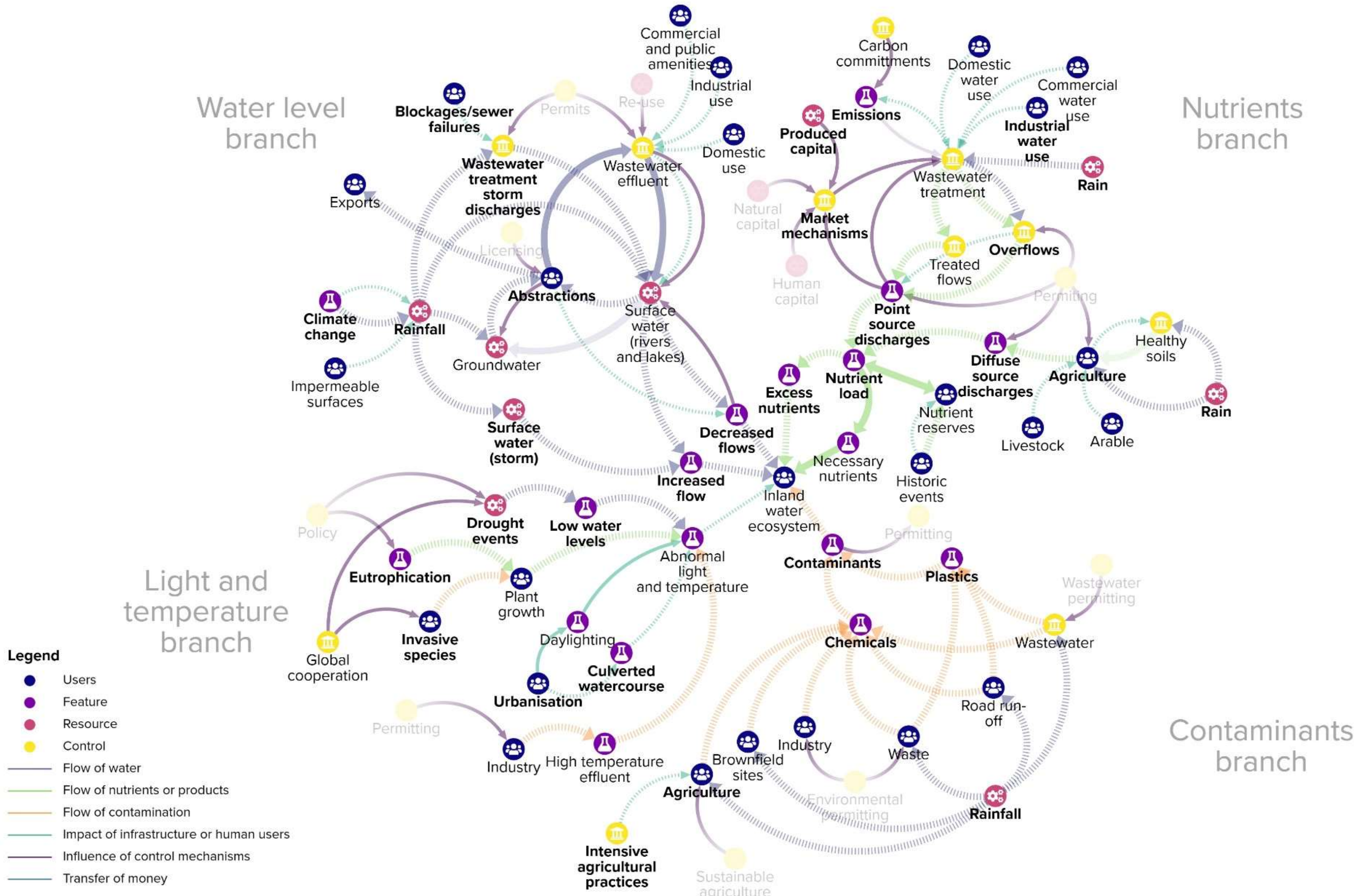


Figure 4-7: Environmental perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a MF future scenario

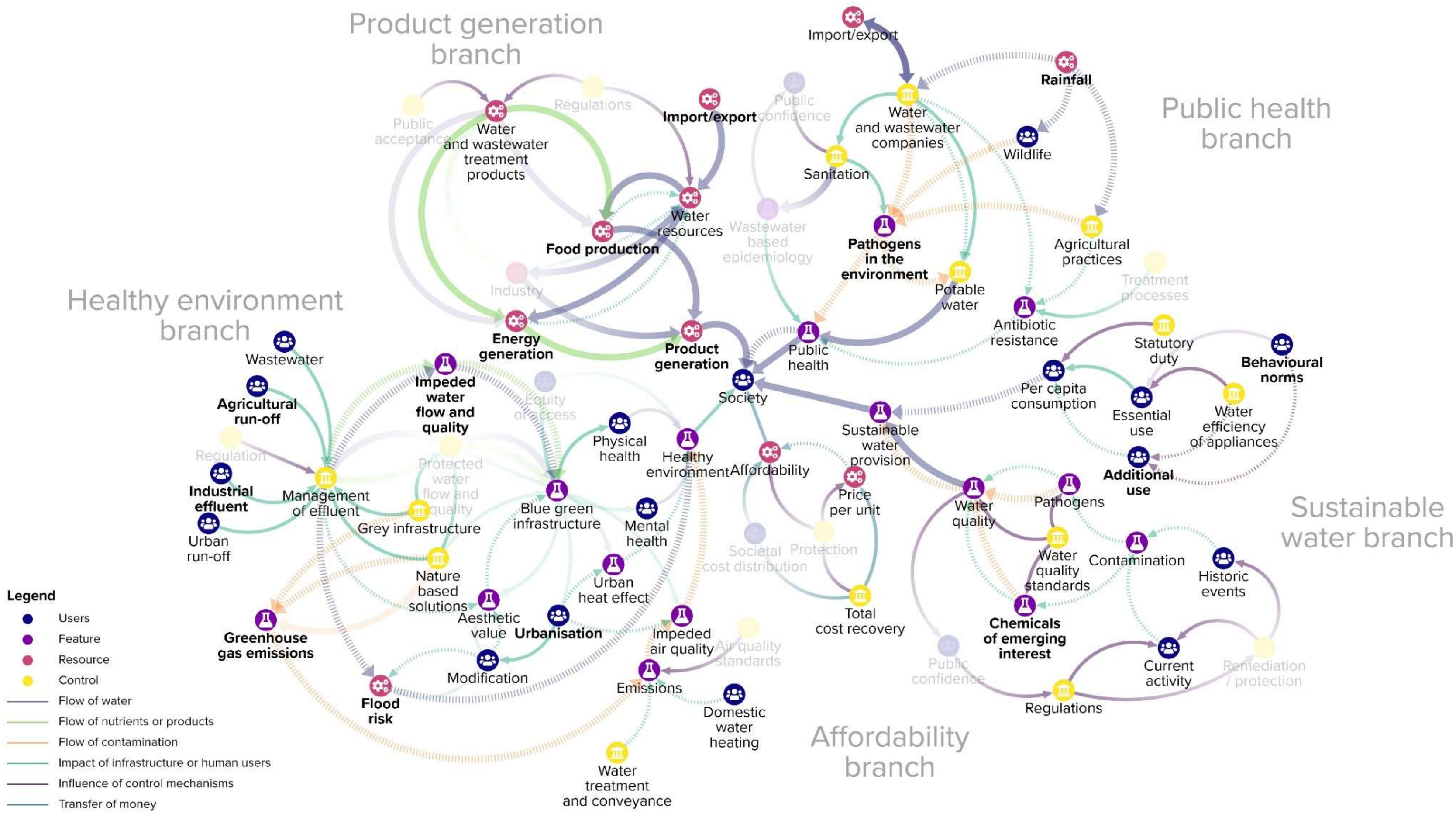


Figure 4-8: Societal perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a MF future scenario

4.2.2 Policy reform (PR)

At the global scale

This is the second of the future scenarios which is considered a 'conventional world'; whilst it represents extremes it is aligned with current global practices. Within a PR future, policy and regulatory frameworks are utilised through strong governance systems to provide environmental protection whilst ensuring economic growth and the eradication of poverty. This focus on equity, and in particular distributional equity leads to reduced conflict at local and global scales thereby supporting geo-political stability. There is a policy-driven focus on enabling a fair, formal economy which incorporates the growth of natural capital (Gallopín et al., 1997, Hunt et al., 2012).

Policy instruments and global decision-making combine to drive reductions in greenhouse gas emissions however the impact is shallow due to a number of contributing factors, not least of which is the scale of change required whilst retaining public support. There is no overall change in population which, combined with a continuation of market-driven consumerism and global economic growth, continues to exert stress upon planetary boundaries. Growth in the provision of renewable energy only manages to mitigate this impact as overall energy demand increases at a similar rate (Gallopín et al., 1997, Hunt et al., 2012).

An emphasis on natural capital and environmental protection within the policy framework, combined with technology transfer and sharing of best practice leads to a moderate decrease in pollutants, water stress and deforestation globally. Although this has the potential to lead to substantial impacts, these do not become apparent due to a stabilised population and continuation of consumerism (Gallopín et al., 1997, Hunt et al., 2012). Therefore, at the global scale the impacts of a policy-driven approach are moderated by consumer behaviour and population trends.

At the inland surface water system scale

At the inland surface water system scale within the UK the impacts of a PR future scenario manifest as the impacts of and response to a policy-driven regulatory system (Figure 4-9). A strong emphasis on social equity in policy increases public confidence whilst increasing policy-driven awareness of natural capital and ecosystem services elevates the value of blue-green infrastructure. Core services are delivered through social enterprise to address social equity and fair societal cost distribution; however, market mechanisms drive the use of private finance for innovation.

Policy direction increases the use of technology, sharing best practice and technology transfer as well as new developments. This is targeted to reduce the impact of increased consumption through growth in renewable energy and low-water technologies including appliance labelling and increasing transparency over water use. The impacts of this approach lead to an overall reduction in water use, however this is variable based on the ability to replace goods and a resistance to adopt new behaviours associated with a backlash against top-down policy.

Despite a strong policy framework to improve environmental conditions all impacts are tempered by market-driven institutions and power structures which mimic current conditions. A focus on natural capital and ecosystem services supports environmental protection approaches, however this is limited as the drive to remain within planetary limits intensifies agriculture, the effects of which are not mitigated by regulation. Within the urban environment

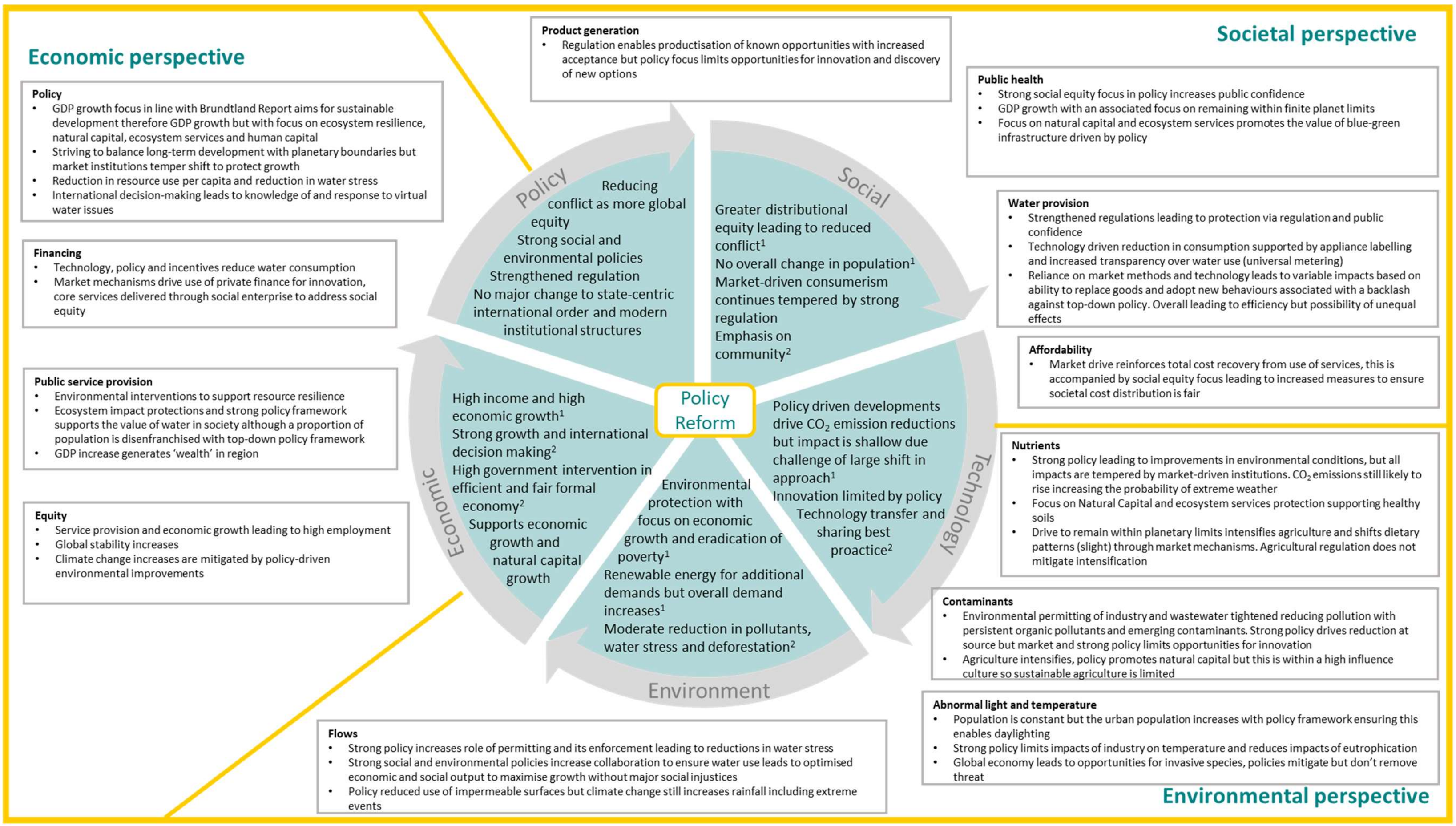


Figure 4-9: Translation of global trends in PR future scenario to the UK surface water system scale (In image references 1 - Gallopín et al. (1997) , 2- Hunt et al. (2012)

policy measures are more effective with increased levels of daylighting and decreased impacts associated with industrial effluent despite increasing urbanisation.

PR influences on relationships across the perspectives of environment, society and economy

Within 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 (Figure 4-10). Therefore, monetary value is prioritised, however this is tempered by policy structures concerning planetary boundaries providing a trade-off between policy and profit generation. Geo-political 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 (Figure 4-11) however economic activity, and a drive for economic growth results in detrimental relationships persisting. 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 (Figure 4-12).

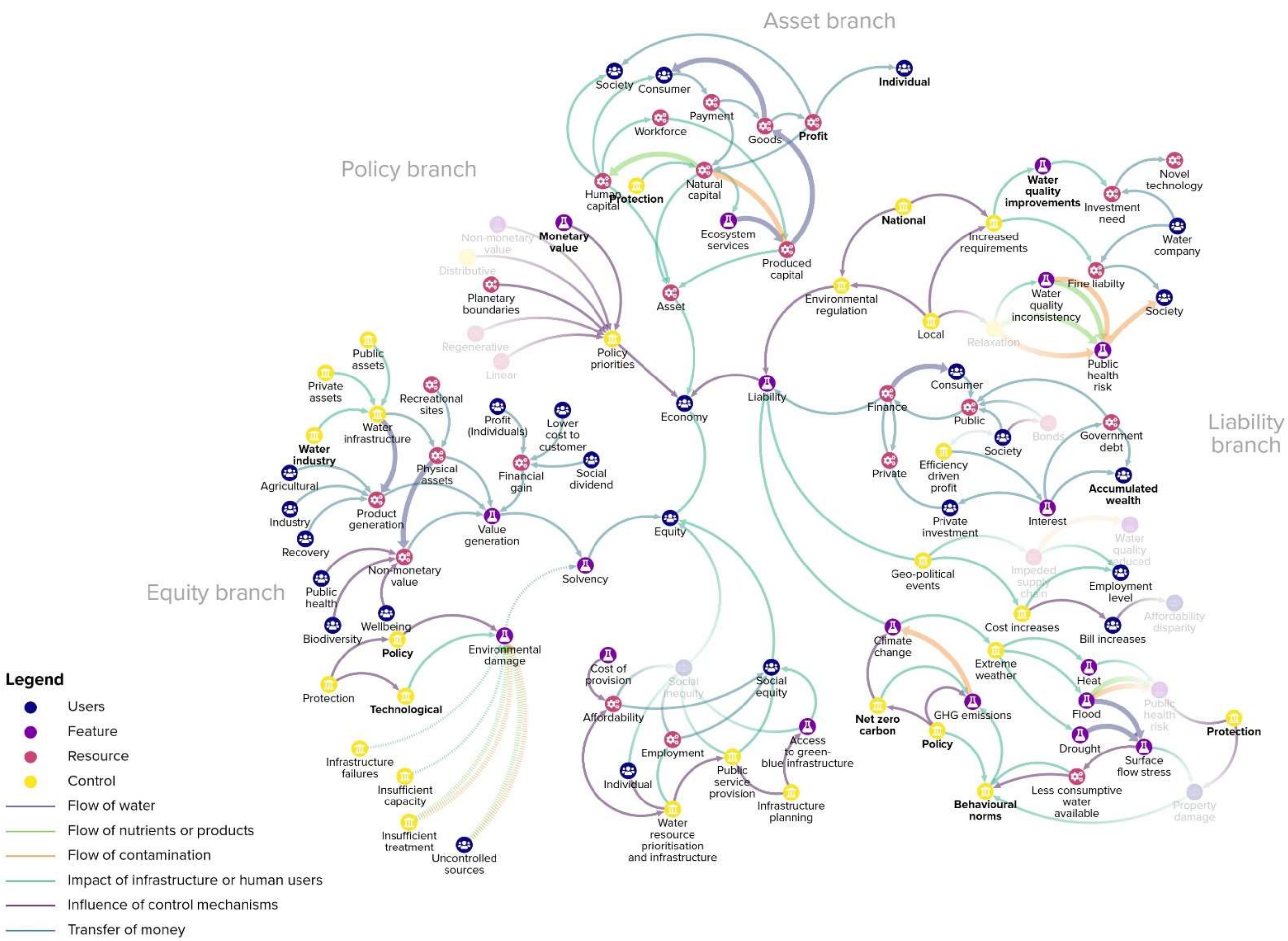


Figure 4-10: Economic perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a PR future scenario

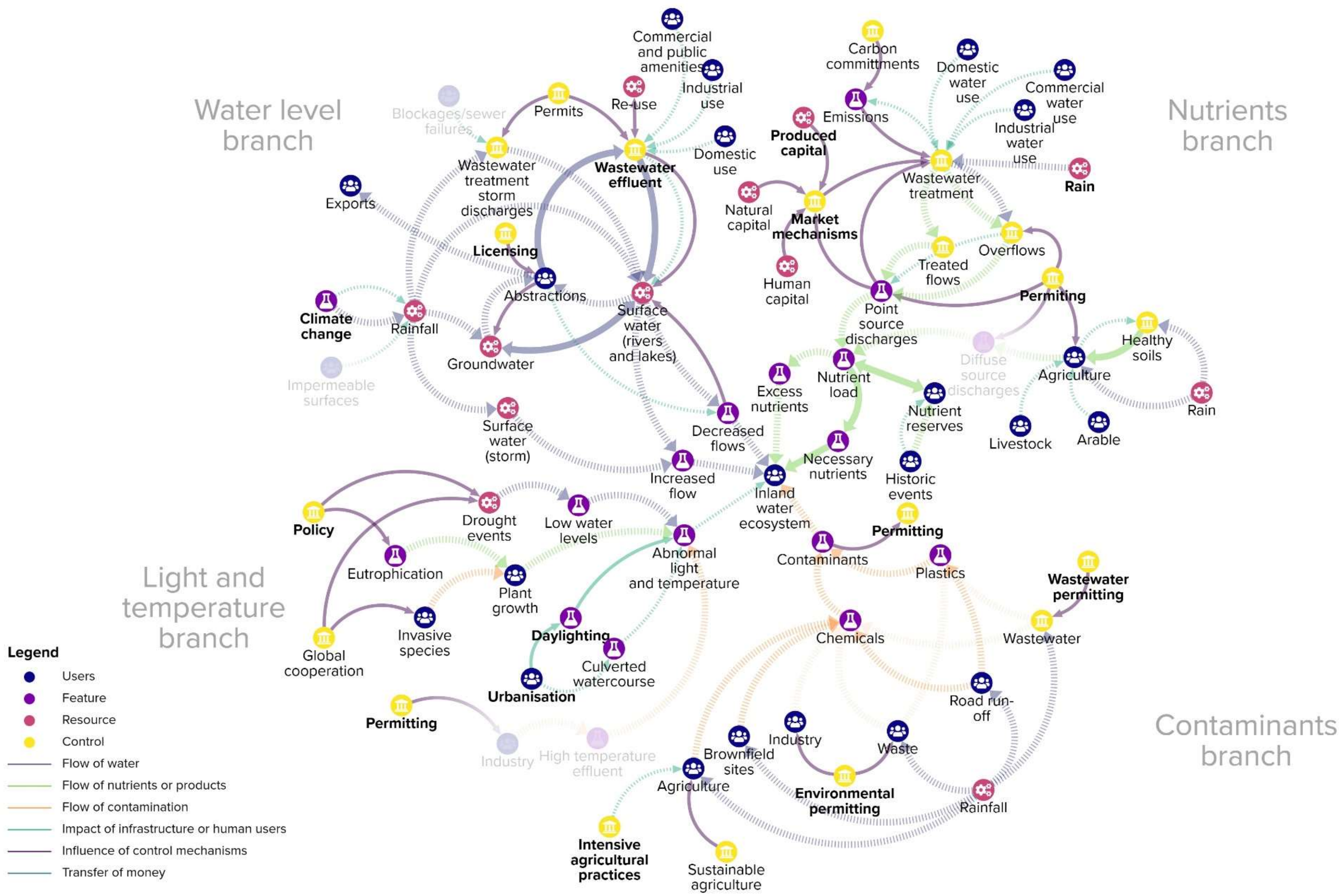


Figure 4-11: Environmental perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a PR future scenario

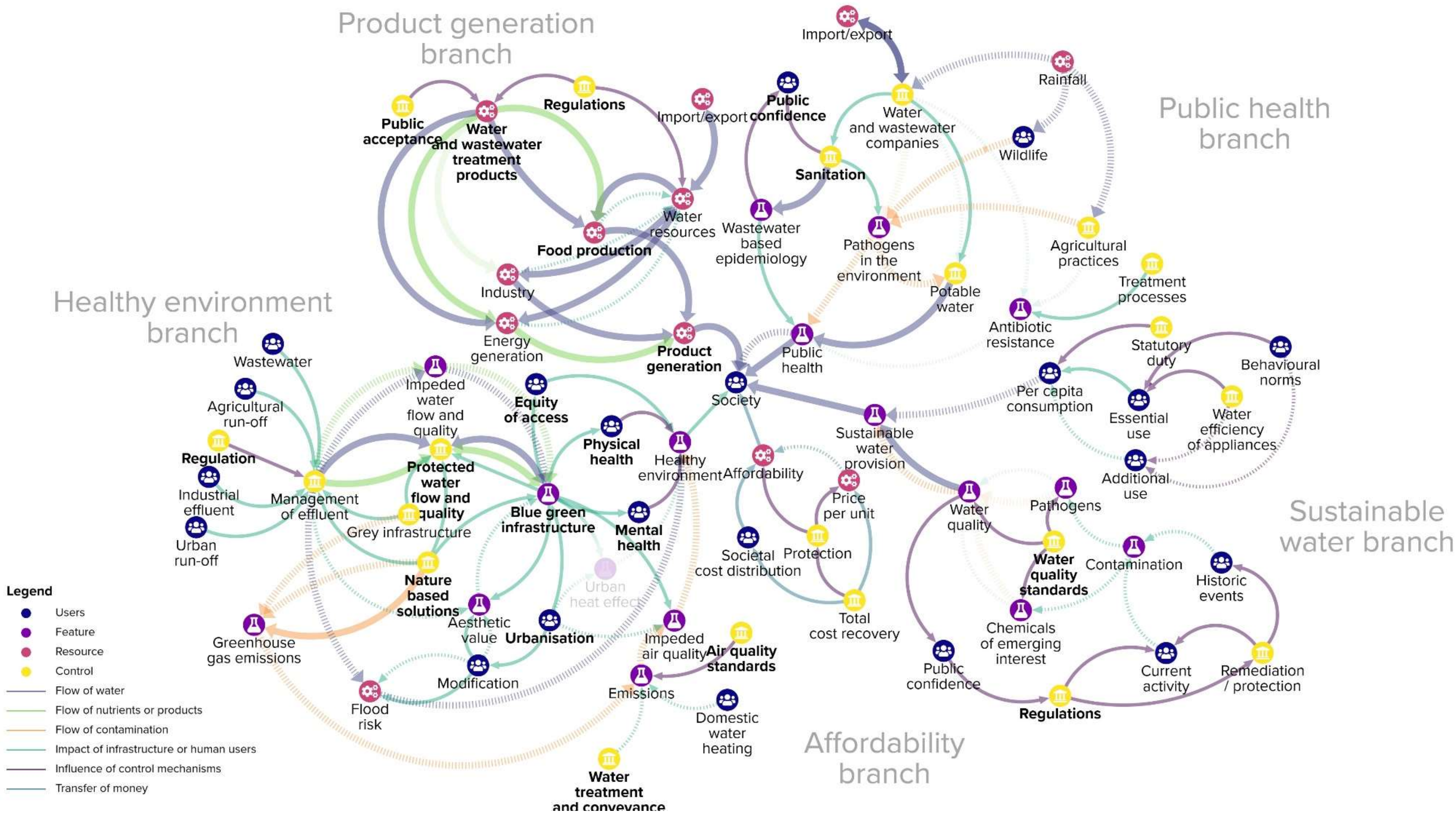


Figure 4-12: Societal perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a PR future scenario

4.2.3 Fortress World (FW)

At the global scale

The first of the scenarios to be considered that is more divorced from the current situation FW represents a scenario in which the impacts become more extreme. This is a scenario where the structures in place currently have broken down and society is segregated into the 'haves' and the 'have nots'. A '*Barbarism'* scenario, as described by Gallopín et al. (1997), this is an authoritarian response to the threat of complete breakdown in order to provide protection to those with power and influence. National decision-making has disintegrated and there is unfettered expansion of the markets with ramifications across society and the environment. There is both low global equity and low localised equity with a proliferation of enclaves for the rich and powerful. As a result, social conflict is high and there is mass migration which elicits a military response (Gallopín et al., 1997, Hunt et al., 2012).

Access to technology is guarded with restrictions in place for the poor masses. A focus on limiting access and ensuring security for the elite leads to a stagnation in the level of technology itself with limited innovation and development to meet emerging challenges. There is however a growing interest in geo-engineering as a means to mitigate the impacts of climate change (Gallopín et al., 1997, Hunt et al., 2012).

Despite this the occurrences of floods and droughts are increasingly frequent and severe, with impacts experienced differently both globally and locally as military, emergency responses insulate the rich and powerful. Strategic resources are kept under military control to ensure access within enclaves and maintain the lifestyle of the privileged 'haves' (Gallopín et al., 1997, Hunt et al., 2012). A breakdown of international and national governance structures has led to divisions across global societies and a force-based control mechanism to prevent further societal breakdown.

At the inland surface water system scale

A FW scenario involves fracturing of societal structures at the local as well as a global scale (Figure 4-13), the disintegration of national decision-making leads to the disintegration of public service provision including water and sanitation services. Control measures and a lack of access are utilised to reduce consumption by the masses whilst protection measures supported by the military are used to ensure continued access within rich enclaves. Water is not valued until it becomes scarce, therefore there is no centralised effort to protect water as a resource for all and instead all water becomes commodified.

The intensification of agriculture combined with rural poverty leads to soil damage and high rates of fertiliser, pesticide and agricultural pharmaceutical use, which when combined with the impacts of climate change, increase levels of diffuse pollution from both nutrients and other contaminants. There is a (limited) technological response to threats which is managed by authority and military force to protect those with power and influence. This is accompanied by a de-prioritisation of nature-based solutions and a disparity of access to nature. What nature remains undamaged by human activity is carefully managed and access is restricted.

The breakdown of centralised management and subsequent prioritisation of protection for the rich and powerful within elite enclaves leads to the use of end-of-pipe, supply side protection against contamination as centralised sources become increasingly difficult to manage and protect. Therefore, the environmental impacts are high and predominantly unmitigated. These impacts are exacerbated by extreme global climate change leading to the changes in the

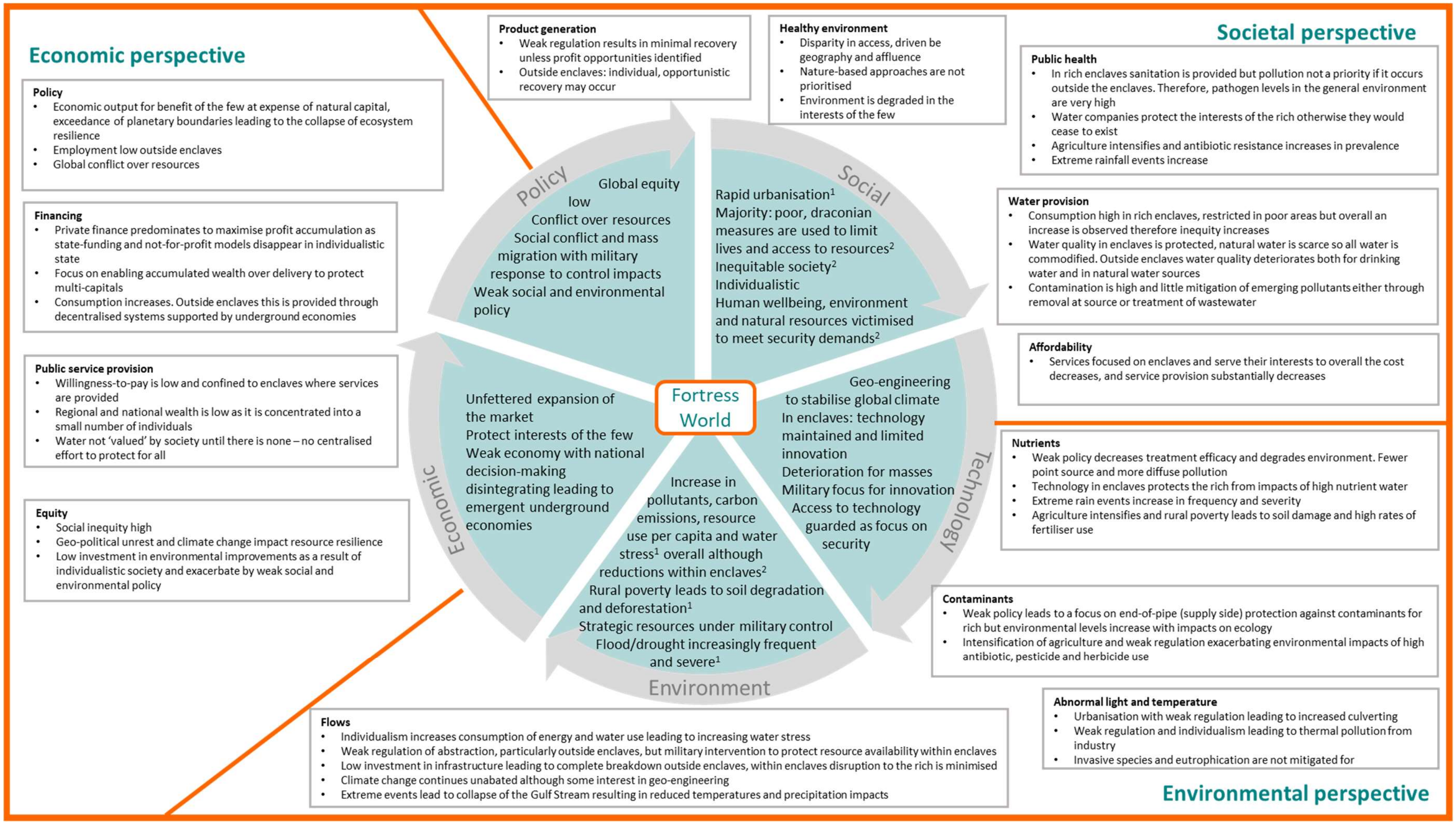


Figure 4-13: Translation of global trends in FW future scenario to the UK surface water system scale (In image references 1 - Gallopín et al. (1997) , 2- Hunt et al. (2012)

Atlantic Meridional Overturning Circulation (AMOC) and subsequent increases in the frequency and severity of flooding and droughts (Met Office, 2019).

FW influences on relationships across the perspectives of environment, society and economy

In a FW future scenario, a breakdown of social structures has led to the development of enclaves with very different outcomes (Figure 4-14). Within the 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 (Figure 4-15). The societal impacts of this are mixed based on societal sector increasing the inequity experienced throughout the population (Figure 4-16).

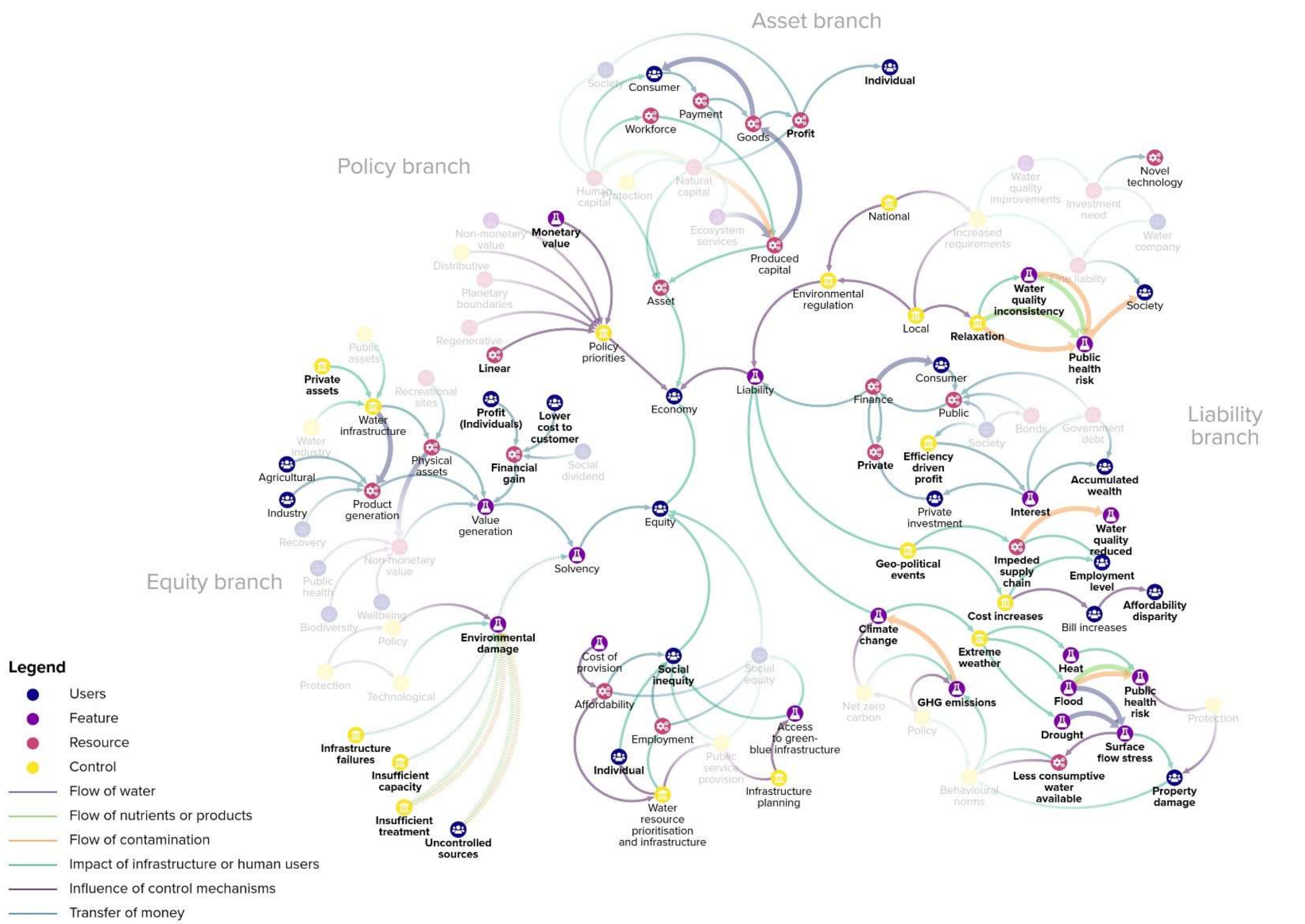


Figure 4-14: Economic perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a FW future scenario

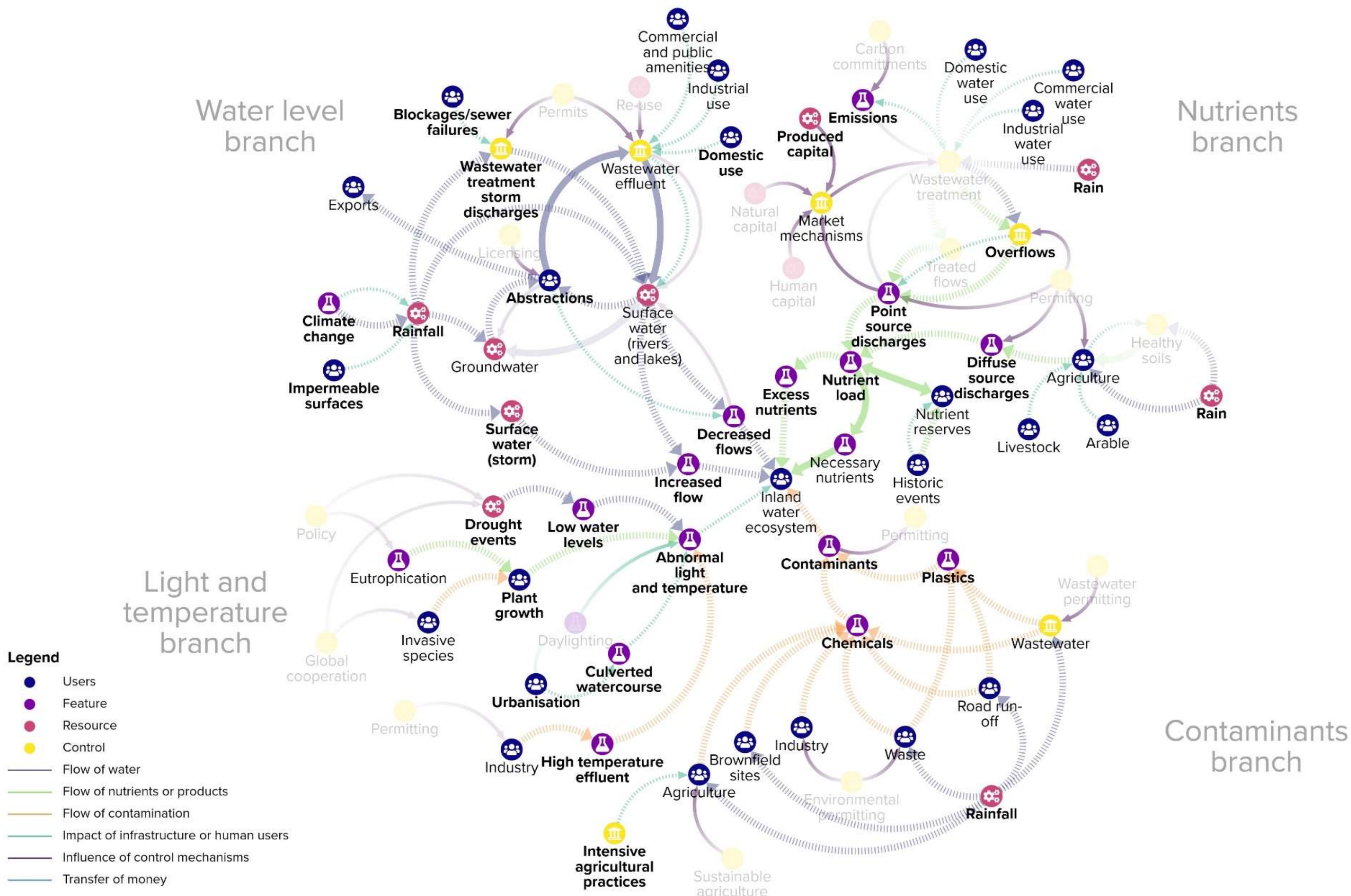


Figure 4-15: Environmental perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a FW future scenario

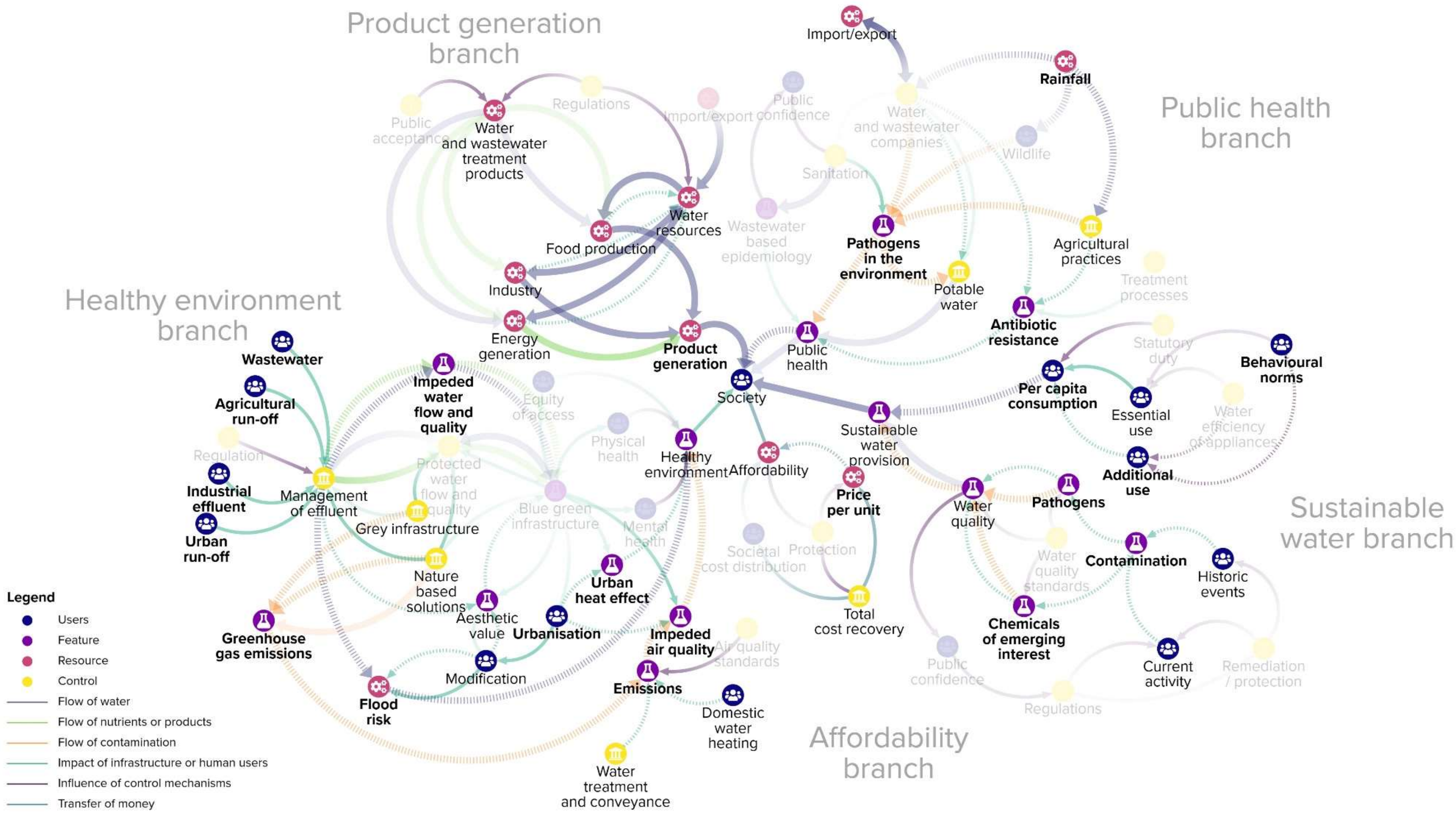


Figure 4-16: Societal perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a FW future scenario

4.2.4 New sustainability Paradigm (NSP)

At the global scale

Whilst the FW scenario represented a future in which characterised by the breakdown of societal structures, the NSP scenario is one of the *'Great transitions'* described by Raskin et al. (2002), in this case a values-led transformation for humane globalisation (Gallopín et al., 1997). There is an emphasis on long-term approaches to address global challenges and a focus on non-materialistic economic development. The use of markets, although present, is constrained by social, cultural and environmental goals to enable transformation characterised by community connectedness (Gallopín et al., 1997, Hunt et al., 2012, Raskin et al., 2002).

There is a transformation in residential areas to be either urban or rural with a disappearance of the sub-urban environment, this is combined with urban redevelopment to generate integrated settlement. Sustainable technology and innovation growth, with global cooperation, acts as an enabler with particular emphasis on technology to support decentralisation to meet evolving requirements (Gallopín et al., 1997, Hunt et al., 2012, Raskin et al., 2002).

Global mechanisms for wealth redistribution and distributed governance create the conditions for a more equitable global society. This is combined with strong societal agency, universal implementation of polluter pays, increased transparency over virtual water consumption to increase adoption of cleaner production methods and sustainable agriculture leading to an overall reduction in GHG emissions (Gallopín et al., 1997, Hunt et al., 2012, Raskin et al., 2002).

At the inland surface water system scale

Water is highly valued due to its essential nature, this supports a high level of willingness-to-pay which is enabled by mechanisms to ensure affordability throughout the community. There is an emphasis on collaboration and community which feeds into policies and a sense of ownership and joint responsibility. At an organisational level there is inclusion of multi-capitals at all levels, including the definition of economic growth, and financing of water and sanitation services is achieved through social enterprise funding models (Figure 4-17).

A combination of decentralisation, regulation and public pressure leads to the development and implementation of fit-for-purpose measures that adapt to changing requirements both in terms of treatment and service standards but also in the regulation that supports them. This ultimately leads to rising environmental and public health standards. There is a sustainability-driven innovation boom that incorporates and enables a growth in the deployment of nature-based solutions and water reuse. This is complemented by a behavioural shift to material sufficiency that is a characteristic of NSP.

These measures applied at local and global levels lead to the impacts of climate change either plateauing or reducing, thereby minimising the need to adapt to the direct impacts of climate change or mitigate for the indirect impacts associated with increased run-off. This is further supported by a move towards sustainable agriculture which leads to reductions in levels of nutrients, antibiotics, pesticides and herbicides.

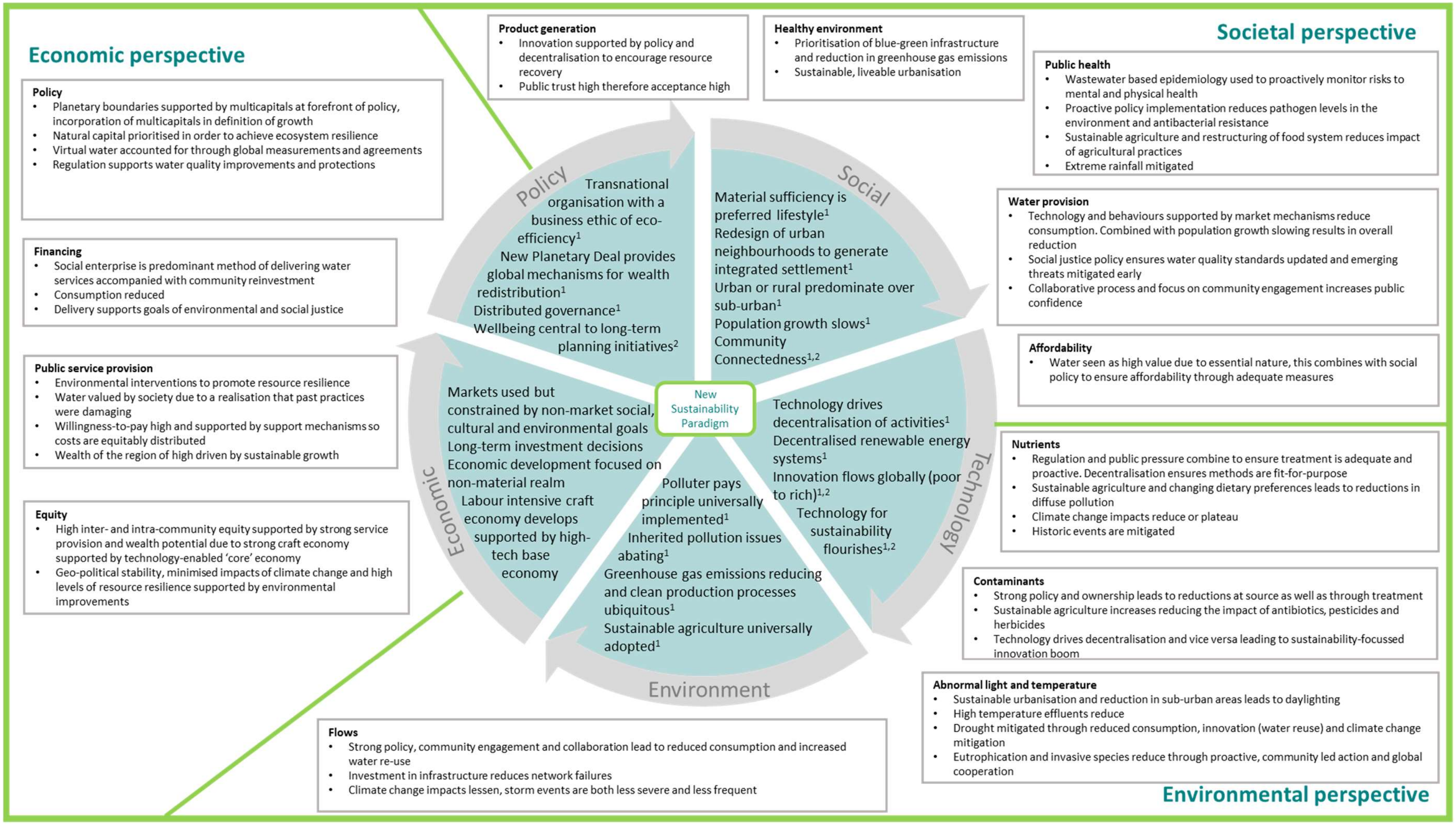


Figure 4-17: Translation of global trends in NSP future scenario to the UK surface water system scale (In image references 1 - Gallopín et al. (1997) , 2- Hunt et al. (2012)

NSP influences on relationships across the perspectives of environment, society and economy

As the NSP future scenario represents a focus on planetary boundaries within a regenerative and distributive economy, payment for water and wastewater services is equitably distributed with payment protections and social dividends in place (Figure 4-18). This is supported by global agreements over GHG 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 (Figure 4-19). This is mirrored from a societal perspective, where a combination of behaviours along with policy and infrastructure mechanisms enable equitable mental and physical health outcomes (Figure 4-20).

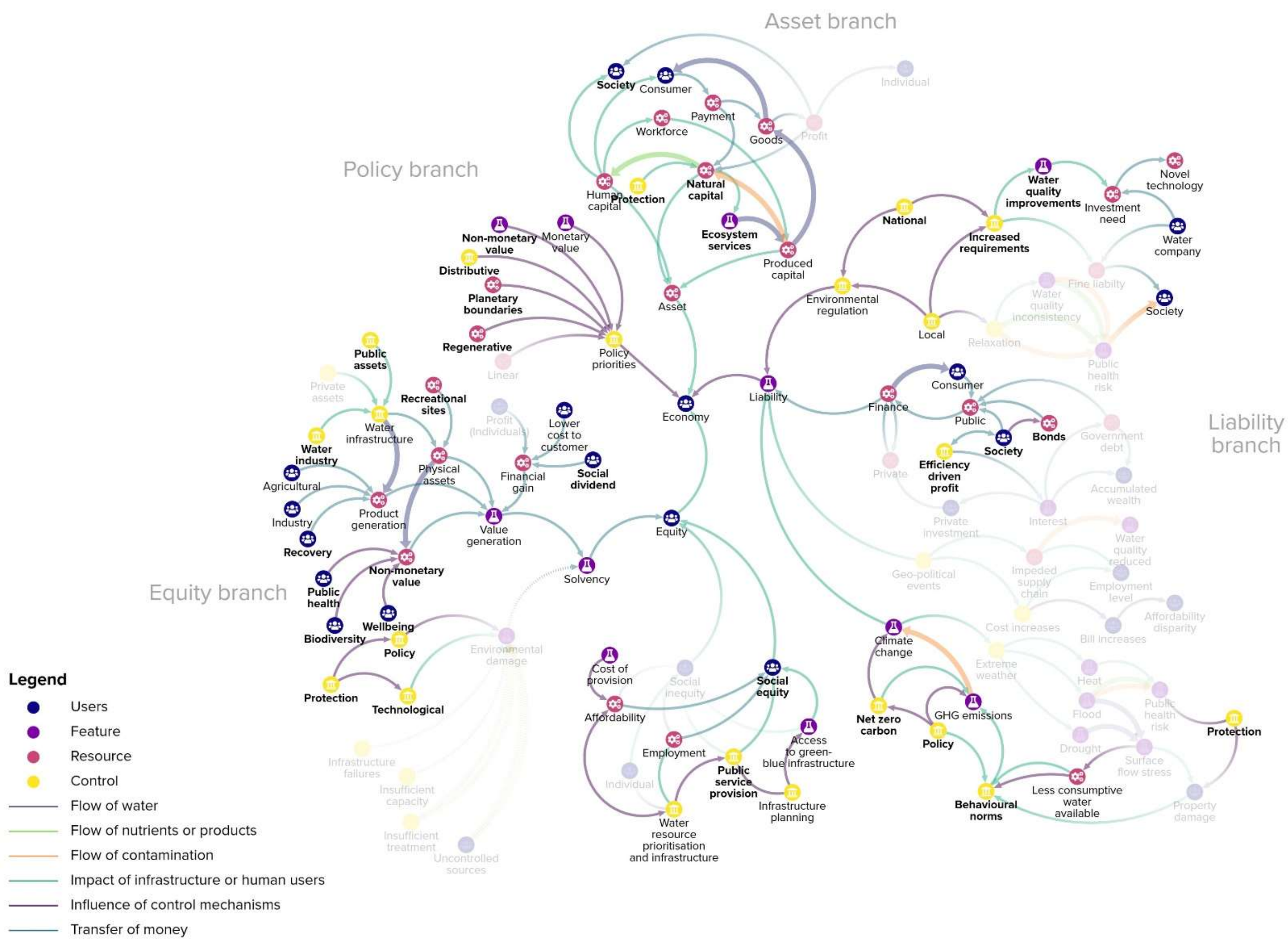


Figure 4-18: Economic perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a NSP future scenario

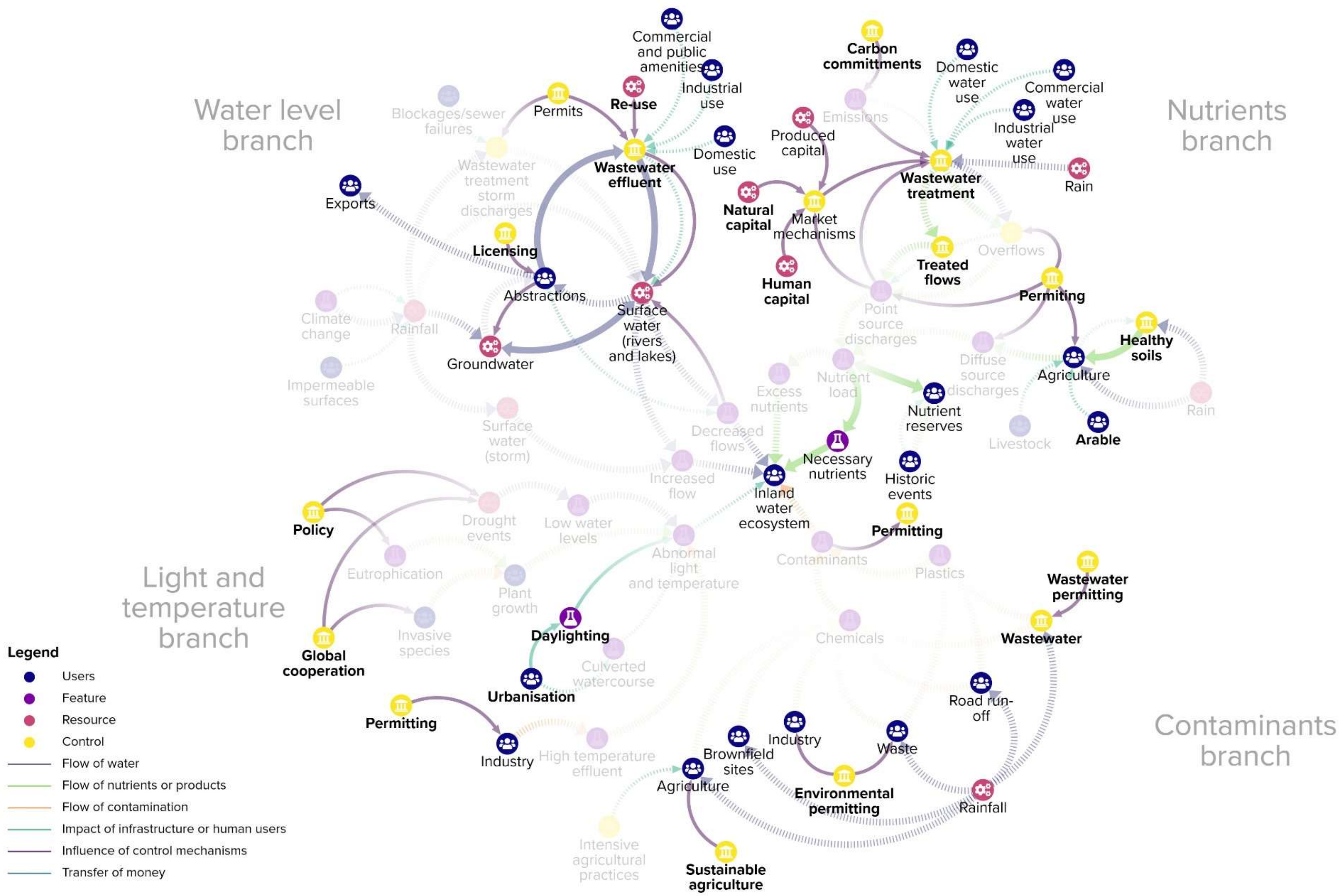


Figure 4-19: Environmental perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a NSP future scenario

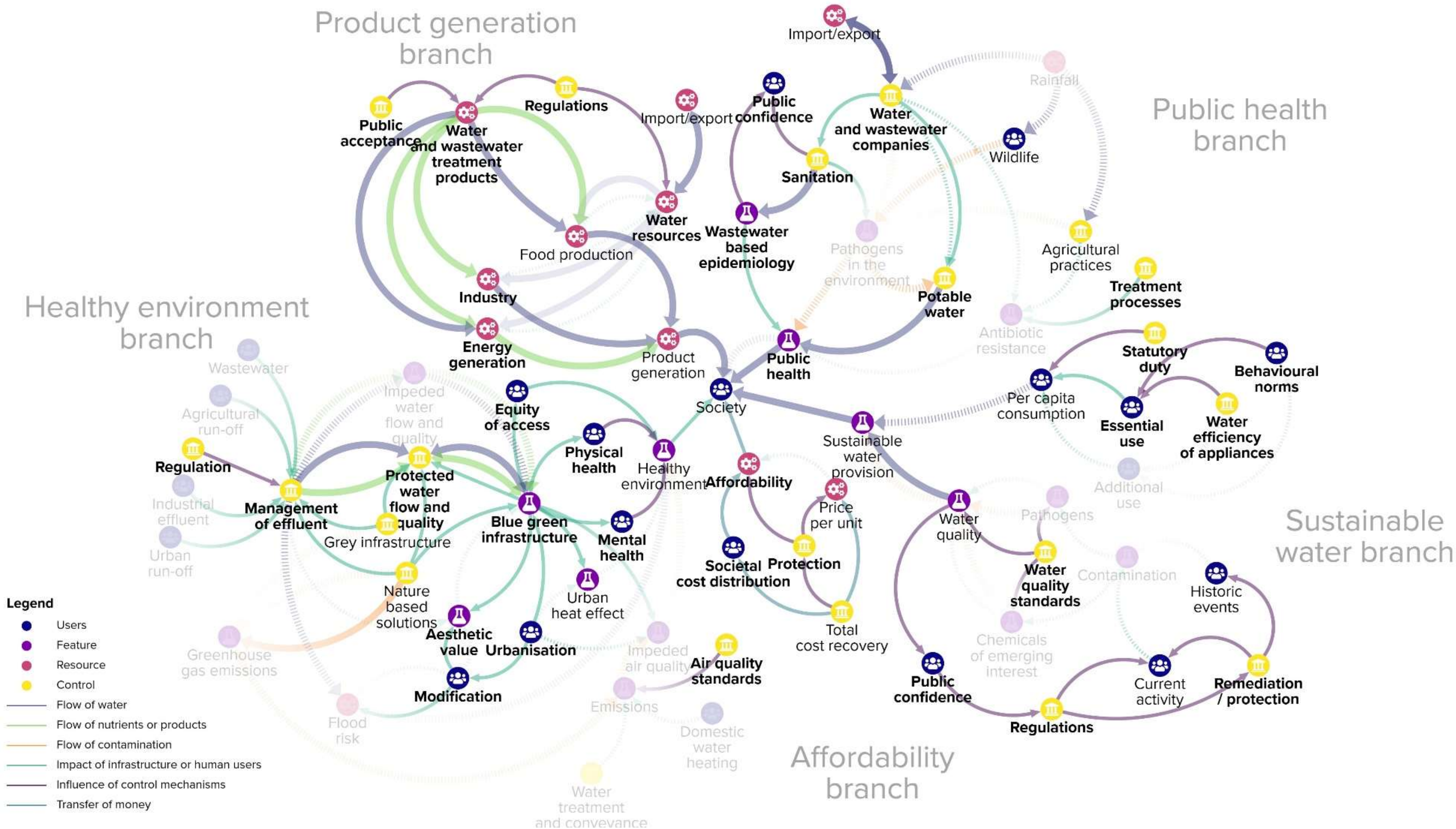


Figure 4-20: Societal perspective system map indicating strengthening (emboldened) and weakening (faded) relationships under a NSP future scenario

4.2.5 Variations across future scenarios

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. MF and 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 (Gallopín et al., 1997, Hunt et al., 2012, Raskin et al., 2002). 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. Through varying the strength of relationships to reflect future scenarios the breadth of impacts can be ascertained, including the conditions under which interventions and infrastructure will operate.

There is a wide spectrum of organisational forms within potential futures, equally there is variation in behavioural and technological approaches with consequential impacts on societal and environmental outcomes. A NSP scenario is shown, through system maps, to be the most supportive to environmental justice derived outcomes, at the other end of the spectrum FW is seen to be the least supportive. Whilst this is unsurprising the system maps enable driving forces for these shifts to be uncovered; these key relationships require further investigation.

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. However, they may be classed as 'horrendograms', a term coined in response to the generation of overwhelming visualisations 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're 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.”

“…there are a lot of variables there…I don't 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.”

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 4-21).

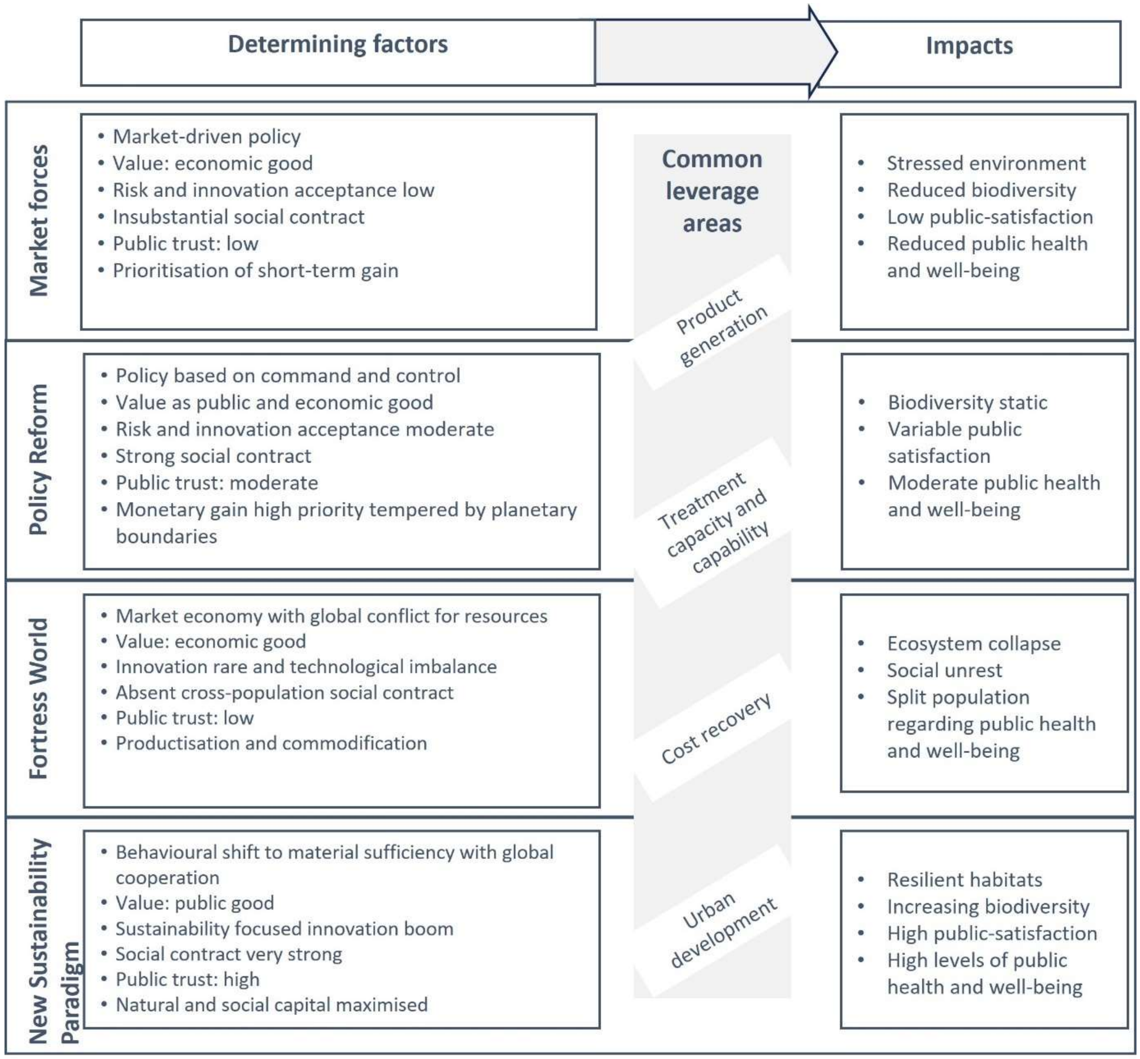


Figure 4-21: Impact chains demonstrating key leverage points across four future scenarios

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 4-22) that would depict the most influential causative relationships and could be used effectively to illustrate and analyse the system. Central to the conceptual model are relationships associated with behaviours, attitudes and policies that closely relate to social justice issues and reflect the impact human interaction has on the natural water system.

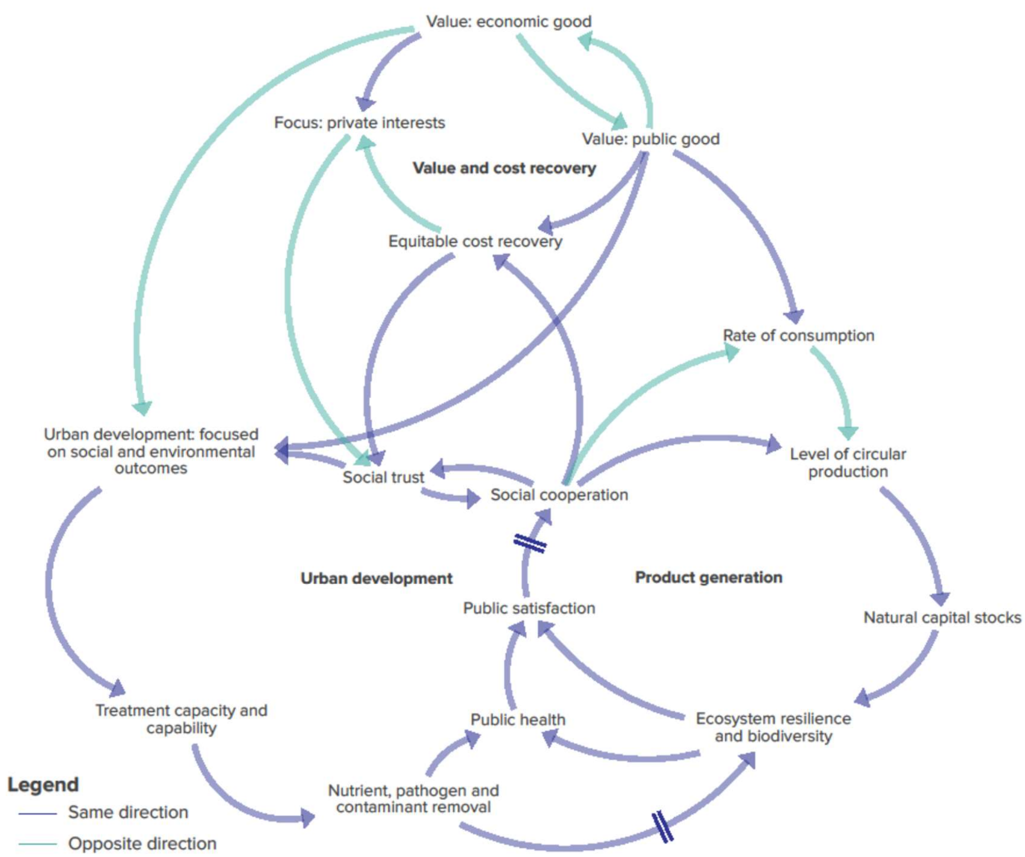


Figure 4-22: Conceptual model showing loops of value and cost recovery, product generation and urban development (incorporating treatment capacity and capability)

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 privatisation, the structuring of which positions water as an economic good. This increase in influence of the 'value: economic good' node has two paths of impact which will be discussed in turn. Firstly, it causes an increase in focus on private interests and individualistic tendencies. This leads to a decrease in social trust and social cooperation, and consequently 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 of the capacity and capability of water and wastewater infrastructure. This leads to reductions in removal of nutrients, contaminants and pathogens with consequent impacts on decreasing public satisfaction, social cooperation and social trust and a further decrease in 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 privatisation leading to prioritisation of the economic good water provides, ultimately leading to decreasing equity in cost impacts. Financialisation mechanisms have increased the focus on profit generation and biased investment decisions to capital investment over operational expenditure, with impacts on long term performance. Additionally individualistic behaviours 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 prioritisation 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 H., 2023), ultimately leading to decreasing public satisfaction and trust (Consumer Council for Water, 2021b) and adversely impacting 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.

4.4 The role of indicators

CLD has been used to understand key points of interaction, or leverage, within relationships of environment, society and economy in the surface water system. Whilst this provides a structure for analysing system impacts, identifying areas of need for action or intervention is more appropriately provided through indicator-based assessments. The following section details the results of analysis of indicators within the literature and their applicability to the surface water system when applying an environmental justice lens to assessments. The assessment was based on ten key questions, derived from future scenario and CLD analysis and detailed in Section 3.6.2.

4.4.1 Literature analysis: trends and observations

A total of 713 indicators were identified within the literature. Within these there were 262 indicator groups spread across 53 categories within the umbrellas of environment, society and economy. 91 of the indicator groups were related to the surface water system, with 51 of these also related to environmental justice.

Indicators which were categorised within the literature as economic measures predominantly involved GDP either as the entirety of the indicator, or as a component to another value such as water consumption per value of GDP (Liu et al., 2020, Ren et al., 2021). Typically, non-monetary forms of value were more likely to appear as part of environmental or social indicators. For the purpose of this assessment some have therefore been allocated to the economic umbrella to reflect a broader definition of value.

4.4.1.1 Environmental perspective

Environmental protection is frequently provided through regulation. In the UK this is held within legislation such as the UWWTD (Directive 91/271/EEC, 1991), WFD (Directive 2000/60/EC, 2000) and others. These set out requirements to mitigate the impacts of anthropogenic water consumption and subsequent return of wastewater to the environment. However, their implementation within the water sector is tempered by affordability restrictions and cost benefit analyses (Byatt, 2013). Progress is being made to enable such analyses to incorporate non-monetary value creation within assessments through the calculation of natural capital and multi-capital approaches (Acosta et al., 2020, British Water with the support of Atkins, 2022, Dasgupta, 2021, Fenech et al., 2003).

Table 4-3 demonstrates the prevalence of indicators that represent the quantification of resource availability, anthropogenic consumption of that resource and the composition of wastewater re-entering the surface water system. Comparatively there is little attention to the outcomes this provides to ecosystems, for example thirteen authors include indicators relating to the availability of water resources, yet six discuss indicators related to the measurement of biodiversity. This, however, may be influenced by the availability of data, with biodiversity data receiving less historic interest and being geographically and temporally fragmented (UKEOF, 2008).

Table 4-3: Summary of environmental indicators within the literature. Bold type indicates that this indicator is applicable to an objective of environmental justice within the surface water system

Category	Indicator	Sources
Water resources	**Water footprint**	Francisco et al. (2023), Raya-Tapia et al. (2022), van Leeuwen et al. (2012), Ho and Goethals (2019), Chen et al. (2022)
	Quantification of resources	Chen et al. (2022), Deng et al. (2022), Liu et al. (2020), Lv et al. (2020)
	Ecological and environment water supplement	Deng et al. (2022)
	Water production and capacity	Bălăcescu et al. (2022), Chen et al. (2022), Deng et al. (2022), Fehr et al. (2004), Liu et al. (2020), Namany et al. (2021), Sironen et al. (2014), Sobhani et al. (2022)
	International water basins	Namany et al. (2021)
Water consumption	**Ecological water use ratio**	Chen et al. (2022), Lv et al. (2020), Namany et al. (2021), Sun et al. (2022)
	Virtual water	Namany et al. (2021)
	Domestic, industrial and agricultural consumption	Chen et al. (2022), Deng et al. (2022), Hu and Han (2023), Liu et al. (2020), Lv et al. (2020), Mao et al. (2020), Namany et al. (2021), Ren et al. (2021), Sun et al. (2022), van Leeuwen et al. (2012)
	Consumption losses and efficiency	Liu et al. (2020), Mao et al. (2020), Rogers et al. (2020), van Leeuwen et al. (2012)
Wastewater impact	**Percentage of wastewater discharged in total water resources**	Chen et al. (2022)
	Adherence to quality standards	Buck et al. (2021), Chen et al. (2022), Ho and Goethals (2019), Rogers et al. (2020), United Utilities Water (2023), van Leeuwen et al. (2012)
	Quantification of contaminants and nutrients discharged	Deng et al. (2022), Hellstrom et al. (2000), Schlör et al. (2017)
	Wastewater treatment rate	Li et al. (2019a), Liu et al. (2020), Mao et al. (2020), Ren et al. (2021), She et al. (2022)
	Volume of wastewater discharged	Chen et al. (2022), Chen and Zhang (2021), Deng et al. (2022), Hellstrom et al. (2000), Li and Li (2019), Liu et al. (2020), Ren et al. (2021), Sun et al. (2022)
Environmental protections/regulations	**Presence of protection or legal status covering water systems**	Fehr et al. (2004), Ho and Goethals (2019), Li et al. (2019a)
	Presence of regulation at national or regional scale	Arcadis (2022), Ho and Goethals (2019), Li et al. (2019a), Lizama-Pérez et al. (2018), Mao et al. (2020), Rogers et al. (2020)
Flooding	**Flood frequency index**	Gain et al. (2016)
	Erosion	Fehr et al. (2004)

Energy and greenhouse gas impact	**Emissions within water sector**	Rogers et al. (2020)
	Carbon sequestration	Hu and Han (2023)
	Energy consumption in the production of water	Ho and Goethals (2019), Li et al. (2019a), Namany et al. (2021)
	Contribution of global effects	Hellstrom et al. (2000)
Biodiversity	**Biodiversity account**	Bălăcescu et al. (2022), Rogers et al. (2020), Schlör et al. (2017), Sironen et al. (2014), Sobhani et al. (2022), van Leeuwen et al. (2012)
	Protections in place	Ho and Goethals (2019)
Ecological impact	**Ecological footprint**	Bălăcescu et al. (2022), Sobhani et al. (2022)
	Ecological carrying capacity	Sobhani et al. (2022)
	Burden of contamination	Chen et al. (2022), Liu et al. (2020), Sobhani et al. (2022), Sun et al. (2022)
	Ecological environmental index	Chen et al. (2022), Liu et al. (2020)

Considering the factors that influence environmental justice from an ecological perspective:

- Does the nutrient load entering the surface water system negatively impact the ecosystem?

The nutrient load entering the water system could be measured through either a quantification of nutrients discharged (Deng et al., 2022, Hellstrom et al., 2000, Schlör et al., 2017) or as a comparison against regulatory standards (Buck et al., 2021, Chen et al., 2022, Ho and Goethals, 2019, Rogers et al., 2020, United Utilities Water, 2023, van Leeuwen et al., 2012). The quantity of nutrients alone does not account for the relative impact due to varying characteristics of the water systems, such as size and flowrate. For example, 2kg of phosphorus in the headwaters of a small brook would have a greater detrimental impact than 2kg of phosphorus in a large river with high flowrates. Utilising a comparison against regulatory standards means that the size of the waterbody and the significance of it as a habitat have been incorporated into the generation of thresholds, although the application of standards may be politically influenced. Therefore, whilst not ideal, the latter measure provides a more complete and universal measure by which different water systems, or stretches of water system, could be assessed. However scientific understanding of the impacts of nutrients on river metabolism is developing, in particular in recognition of the complexity of ecosystem relationships and where multiple measures are amalgamated into a combined result (Page et al., 2012). Thus, whilst the use of regulatory standards may not be an ideal benchmark and is influenced both by political pressures and current scientific knowledge, it is a consistent approach that has been reviewed and accepted across multiple countries and has the advantage of being translated to the local scale.

- Are contaminants in the form of chemicals and plastics, including microplastics, present in quantities that negatively impact the ecosystem?

Quantification or assessment of the adherence to regulation is also a typical method of assessment of contaminants ranging from chemicals to coarse solids and microplastics (Buck et al., 2021, Chen et al., 2022, Deng et al., 2022, Hellstrom et al., 2000, Ho and Goethals, 2019, Rogers et al., 2020, Schlör et al., 2017, United Utilities Water, 2023, van Leeuwen et al., 2012). However, this is made more complex by the rapidly growing understanding of the impacts of these contaminants, meaning that the regulation is not as mature as for nutrients. For example, the WFD was formulated at a time when there was minimal knowledge of the impact of pharmaceuticals or microplastics, indeed standard forms of measurement and treatment technologies are still emerging (Brammer et al., 2018, Duis and Coors, 2016, Onoja et al., 2022). This has led to a delay in which scientific knowledge is developed, and the impacts understood, before regulation can be updated.

- Is flow sufficient to maintain life and support the ecosystem throughout the year?

Within the literature an assessment of water levels is associated with the utilisation of water as a resource (Chen et al., 2022, Deng et al., 2022, Francisco et al., 2023, Ho and Goethals, 2019, Liu et al., 2020, Lv et al., 2020, Raya-Tapia et al., 2022, van Leeuwen et al., 2012) with some inclusion of measures of water scarcity and drought (Gain et al., 2016, van Leeuwen et al., 2012) and water supplementation (Deng et al., 2022). Therefore, the impacts of water levels on freshwater biological health as a result of indirect human activity, such as climate change leading to more extreme weather patterns, are not extensively represented in existing indicators due to an anthropocentric interpretation of water resource requirements.

- Does anthropogenic modification of the surface water system, and surrounding environment, impact light levels or temperature to the extent that they negatively impact the ecosystem?

Within the literature, indicators relating to light and temperature conditions within the water system were notable by their absence, even though these factors have impacts on biodiversity (Battin et al., 2023, SEPA, 2015). Impacts are variable along the length of a waterbody with intensification and abatement as local conditions change (Hannah and Garner, 2015), this is unlike nutrient and contaminant additions which are predominantly additive. Therefore, there are difficulties in the definition of a suitable indicator for this characteristic that could be applied appropriately. Nevertheless, the impacts, particularly in urban areas can be substantial (CIWEM, 2007, Wild et al., 2011).

While the above factors *influence* biodiversity, a direct measure of biodiversity could be considered to be a separate indicator (Bălăcescu et al., 2022, Rogers et al., 2020, Schlör et al., 2017, Sironen et al., 2014, Sobhani et al., 2022, van Leeuwen et al., 2012). This is an important indicator to provide an overall impact on the surface water system from a combination of factors. However, data would need to be available at an appropriate scale to enable interrogation for individual surface water systems and subsystems. Additionally, inclusion of an indicator that could be considered an outcome of the impacts of other indicators has the potential to provide weighting or aggregation within the overall interpretation of the analysis and as such should be avoided.

4.4.1.2 Societal perspective

From the perspective of society, the emphasis changes from characteristics of the surface water system into focusing on the impacts this has on human health, and therefore provision of water and sanitation services across the population. This is reflected in the statutory duty of water companies and is increasingly considered in urban development research (Rogers and Hunt, 2019).

Table 4-4 summarises the range of indicators that relate to society's interaction with the surface water system. Indicators were excluded from this analysis if they indirectly, rather than directly, relate to the surface water system, for example those related to food production and energy generation. Indicators directly related to the surface water system ranged from the risks posed by environmental events to built infrastructure (Buck et al., 2021, Deng et al., 2022, Hellstrom et al., 2000, Rogers et al., 2020, United Utilities Water, 2023), and the resilience and robustness of water infrastructure when facing a changing climate (Deng et al., 2022, Fehr et al., 2004, Hellstrom et al., 2000, Liu et al., 2020, Rogers et al., 2020, United Utilities Water, 2023, van Leeuwen et al., 2012), to the influence of surface water systems on public health

Table 4-4: Summary of societal indicators within the literature. Bold type indicates that this indicator is applicable to an objective of environmental justice within the surface water system

Category	Indicator	Sources
Green infrastructure	**Green space per capita**	Buck et al. (2021), Chen and Zhang (2021), Liu et al. (2020), Lv et al. (2020)
	Activating connected blue-green space	Rogers et al. (2020)
	Urban green space coverage	Arcadis (2022), Chen and Zhang (2021), Chen et al. (2022), Deng et al. (2022), Liu et al. (2020), Lv et al. (2020), She et al. (2022)
	Proportion of natural reserve area	Chen et al. (2022)
Sanitation	**Access to sanitation**	Bălăcescu et al. (2022), de Brito et al. (2018), Gain et al. (2016), Liu et al. (2020), Sironen et al. (2014), van Leeuwen et al. (2012)
	Wastewater treatment rate, capacity prior to spill	Chen et al. (2022), Deng et al. (2022), Ho and Goethals (2019), Lv et al. (2020)
	Sewer blockage	Hellstrom et al. (2000)
Water supply	**Drinking water of required quality**	Chen et al. (2022), Deng et al. (2022), Fehr et al. (2004), Gain et al. (2016), Hellstrom et al. (2000), She et al. (2022), van Leeuwen et al. (2012)
	Sufficiency of per capita water resources	Bălăcescu et al. (2022), Deng et al. (2022), Fehr et al. (2004), Gain et al. (2016), Hellstrom et al. (2000), Liu et al. (2020), Raya-Tapia et al. (2022), Rogers et al. (2020), Sironen et al. (2014), Sun et al. (2022), van Leeuwen et al. (2012)
	Waterborne outbreaks of infection	Hellstrom et al. (2000)
	Treatment capacity	Fehr et al. (2004), Liu et al. (2020)
Water and wastewater infrastructure	**Multifunctional water infrastructure**	Rogers et al. (2020)
	Density, length and resilience of pipe networks	Deng et al. (2022), Fehr et al. (2004), Hellstrom et al. (2000), Liu et al. (2020), Rogers et al. (2020), United Utilities Water (2023)
	Stormwater separation	Hellstrom et al. (2000), Rogers et al. (2020), van Leeuwen et al. (2012)
	Maintenance	Hellstrom et al. (2000), Rogers et al. (2020), van Leeuwen et al. (2012)
	Integration and intelligent control	Rogers et al. (2020)
	Infrastructure and ownership at multiple scales	Rogers et al. (2020)
Flooding	**Internal flooding**	Hellstrom et al. (2000), United Utilities Water (2023)
	External flooding/flooding of open spaces	United Utilities Water (2023)
	Death toll of flooding disaster	Deng et al. (2022)
Urbanisation	**Infrastructure expansion and investment**	Hu and Han (2023), Schlör et al. (2017)
	Climate robust buildings	van Leeuwen et al. (2012)

	Urbanisation rate	Li and Li (2019), Liu et al. (2020), Lv et al. (2020), She et al. (2022)
Health	**Healthy life expectancy at birth**	Bălăcescu et al. (2022)
	Years of potential life lost	Buck et al. (2021), Sironen et al. (2014)
Public satisfaction/happiness	**Public satisfaction**	Li et al. (2019a)
	Global peace index	Mishchuk et al. (2019)
Equality	**Equitable access across water services**	Rogers et al. (2020)
	Equitable representation of perspectives	Ho and Goethals (2019), Rogers et al. (2020)
Governance	**Water literacy**	Rogers et al. (2020)
	Participative policy and planning processes	Arcadis (2022), Buck et al. (2021), Fehr et al. (2004), Lizama-Pérez et al. (2018), Rogers et al. (2020), van Leeuwen et al. (2012)
	Water is a key element in planning	Rogers et al. (2020)
	Human development index	Mishchuk et al. (2019)
Emergency response	Community preparedness	Rogers et al. (2020)
	Multi-hazard risk index	Buck et al. (2021)
	Risk of 1:50 storm	United Utilities Water (2023)
Population	Natural population growth rate	Chen and Zhang (2021), Deng et al. (2022), Li and Li (2019), Liu et al. (2020), Lv et al. (2020), Ren et al. (2021)
	Population growth	Bălăcescu et al. (2022), Fehr et al. (2004), Liu et al. (2020)
	Urban population density	Deng et al. (2022), Liu et al. (2020)
	Population characteristics (age, disability)	de Brito et al. (2018)

(Bălăcescu et al., 2022, Chen et al., 2022, de Brito et al., 2018, Deng et al., 2022, Fehr et al., 2004, Gain et al., 2016, Hellstrom et al., 2000, Ho and Goethals, 2019, Liu et al., 2020, Lv et al., 2020, Raya-Tapia et al., 2022, Rogers et al., 2020, She et al., 2022, Sironen et al., 2014, Sun et al., 2022, van Leeuwen et al., 2012) and extending into physical and mental well-being (Bălăcescu et al., 2022, Buck et al., 2021, Li and Li, 2019, Mishchuk et al., 2019, Sironen et al., 2014).

Within the literature a number of additional indicators are proposed and utilised including population (Bălăcescu et al., 2022, Chen and Zhang, 2021, de Brito et al., 2018, Deng et al., 2022, Fehr et al., 2004, Li and Li, 2019, Liu et al., 2020, Lv et al., 2020, Ren et al., 2021), urbanisation (Hu and Han, 2023, Li and Li, 2019, Liu et al., 2020, Lv et al., 2020, Schlör et al., 2017, She et al., 2022, van Leeuwen et al., 2012) and emergency response (Buck et al., 2021, Rogers et al., 2020, United Utilities Water, 2023). Whilst these are factors that lead to additional stresses, or changes in use around the surface water system, they are not in themselves considered factors in the ability of a surface water system to enable society to thrive under a definition of environmental justice as defined in Section 2.2. In a similar way indicators related to the application of participative methods (Arcadis, 2022, Buck et al., 2021, Fehr et al., 2004, Lizama-Pérez et al., 2018, Rogers et al., 2020, van Leeuwen et al., 2012) are not in themselves directly related to water systems. These are regional scale factors that measure the wider context within which the surface water system is being considered and as such are necessary for diverse perspectives to be incorporated into the assessment process.

Considering the factors that influence environmental justice from a societal perspective:

- Are water and sanitation services provided equitably across the population in support of public health?

The primary function of water and sanitation services is the protection of public health (Beecher, 1997, United Nations, 2015) and this is mirrored in the indicators found within the literature (Bălăcescu et al., 2022, Chen et al., 2022, de Brito et al., 2018, Deng et al., 2022, Fehr et al., 2004, Gain et al., 2016, Hellstrom et al., 2000, Ho and Goethals, 2019, Liu et al., 2020, Lv et al., 2020, She et al., 2022, Sironen et al., 2014, van Leeuwen et al., 2012). Additionally, wastewater can provide an indication of wider societal risk factors and trends that can be monitored through the growing field of wastewater-based epidemiology. However, there are ethical considerations in the collection and analysis of this data at the surface water system, and sub-system scale due to transparency of data collection and use, as well as privacy concerns, particularly within small and marginalised communities (Bowes et al., 2023, Robins et al., 2022). The consideration of water services can be divided into the equitable provision of good quality potable water and the provision of sanitation services such that environmental pathogen levels do not constitute a risk to the population.

- Is a healthy environment available through equitable implementation of blue-green infrastructure?

The surface water system can act as the basis for blue-green infrastructure within an urbanised environment (Zhao et al., 2020, Zheng et al., 2021), while proximity to blue-green space is known to have positive impacts on air quality (Ascenso et al., 2021, De Vrees et al., 2021, Lafortezza and Sanesi, 2019) as well as on human physical and mental health (Bauwelinck et al., 2020, Bell et al., 2008, De Petris et al., 2021, Giannico et al., 2021, Nawrath et al., 2021, Robinson et al., 2020, Van den Berg, 2017). Indicators within the literature reflect this with a focus on green spaces (Buck et al., 2021, Chen and Zhang, 2021, Liu et al., 2020, Lv et al., 2020, Rogers et al., 2020). However, the presence of green space alone does not reflect the accessibility of green space and the pervasiveness of use across society.

- Does the surface water system contribute to local mental and physical well-being?

The surface water system provides provisioning, regulating, supporting and cultural ecosystem services (Costanza et al., 2017) and these support mental and physical wellbeing within the population that has access to this system (Bauwelinck et al., 2020, Bell et al., 2008, De Petris et al., 2021, Giannico et al., 2021, Nawrath et al., 2021, Robinson et al., 2020, Van den Berg, 2017). Indicators within the literature use life expectancy (Bălăcescu et al., 2022, Buck et al., 2021, Sironen et al., 2014), public satisfaction (Li et al., 2019a, Mishchuk et al., 2019) and equality (Rogers, Ho) to assess these impacts. These indicators assess the combined impacts of multiple factors and need to be considered in combination with equity measures to determine the justice impacts. Additionally, water services, especially wastewater infrastructure, is associated with air quality and atmospheric impacts due to the potential for emissions (Water UK, 2020) and therefore may be contributors to indirect impacts at the local and global scales.

4.4.1.3 Economic perspective

In contrast to environmental and societal perspectives, the economic viewpoint is influenced by the prevailing political, philosophical and ethical context making the consideration of environmental justice from an economic perspective a somewhat challenging prospect. Economic indicators reflect these biases in both the formulation of what is measured and the benchmark. Due to the trend within the 20th and 21st Centuries to focus on productivity and in particular gross domestic product (GDP) as a measure of economic success, this term is persistent throughout many of the economic indicators.

However, in recent decades there has been a movement towards recognition of ecosystem services and multi-capitals as a measurement of monetary and non-monetary value generated from either assets or activities (Costanza et al., 2017, Dasgupta, 2021, Farley and Costanza, 2010). Further consideration should be paid to requirements for funding of public services as there is a need for sufficient and sustainable funding to ensure these services continue to meet society’s needs.

Table 4-5 summarises categories of economic indicators within the literature. These relate to the view of water as an economic good as a provider of resources (Chen et al., 2022, Liu et al., 2020, Ren et al., 2021, Rogers et al., 2020), including recovered resources (Hellstrom et al., 2000, Rogers et al., 2020, van Leeuwen et al., 2012), and a source of employment opportunities both directly and indirectly (Li et al., 2019a, Lv et al., 2020, Mishchuk et al., 2019, Ren et al., 2021, She et al., 2022). Additionally, indicators relate to economic aspects of the provision of water services in infrastructure spend (Arcadis, 2022, Bălăcescu et al., 2022, Chen and Zhang, 2021, Deng et al., 2022, Ho and Goethals, 2019, Li et al., 2019a, Li and Li, 2019, Liu et al., 2020, Lizama-Pérez et al., 2018, Lv et al., 2020, Rogers et al., 2020, Schlör et al., 2017, Sironen et al., 2014, Sun et al., 2022).

Table 4-5: Summary of economic indicators within the literature. Bold type indicates that this indicator is applicable to an objective of environmental justice within the surface water system

Category	Indicator	Sources
Productivity	**Reduction rate of water consumption per unit of industrial added value**	Ren et al. (2021)
	Water related business opportunities	Rogers et al. (2020)
	Water production	Chen et al. (2022), Liu et al. (2020)
	Water consumption standardised of GDP	Liu et al. (2020), Ren et al. (2021)
Affluence	**Provision of employment opportunities**	Li et al. (2019a)
	Engel coefficient	Lv et al. (2020), She et al. (2022)
	Multidimensional poverty index	Mishchuk et al. (2019)
	Proportion of employees in whole society	Ren et al. (2021)
Spending	**Investment in pollution prevention and as a proportion of GDP**	Deng et al. (2022), Ho and Goethals (2019), Li and Li (2019), Lv et al. (2020), Sun et al. (2022)
	Green finance	Arcadis (2022)
	Direct economic cost of flood disaster	Deng et al. (2022)
	Spending in food-energy-water sector	Schlör et al. (2017)
	Foreign Direct Investment ratio in fixed asset investment	Chen and Zhang (2021)
Freedom	**Ease of doing business**	Arcadis (2022), Mishchuk et al. (2019)
	Connectivity	Arcadis (2022)
	Index of economic freedom	Mishchuk et al. (2019)

Water price/public good spending	**Affordability of water pricing**	Arcadis (2022), Fehr et al. (2004), Namany et al. (2021)
	Resourcing and funding to enable societal value	Lizama-Pérez et al. (2018), Rogers et al. (2020)
	Public debt or governmental fiscal pressured	Bălăcescu et al. (2022), Li et al. (2019a), Sironen et al. (2014)
	Sustainable cash flow	Li et al. (2019a)
	Annual construction funds of municipal public facilities	Liu et al. (2020)
Resource recovery	**Sewage sludge use in agriculture**	van Leeuwen et al. (2012)
	Energy recovery from wastewater	van Leeuwen et al. (2012)
	Nutrient recovery	Hellstrom et al. (2000), van Leeuwen et al. (2012)
	Optimised resource recovery	Rogers et al. (2020)

Considering the factors that influence environmental justice from an economic perspective:

- Does the cost of water and sanitation services impact the population equitably?

The affordability of water and sanitation services across the population is a key factor in the equitability of this service, as pricing can have indirect, unjust consequences (Heino and Takala, 2015, Kertous et al., 2022, Luby et al., 2018, Ntengwe, 2004, Olmstead and Stavins, 2009, Shi et al., 2014). This was included within the literature in a measure of affordability of water pricing (Arcadis, 2022, Fehr et al., 2004, Namany et al., 2021) - guidelines on affordability benchmarks are included in the Consumer Council for Water guidelines (Consumer Council for Water, 2021a) as <5% of household income excluding housing costs, or 3-5% within the United Nations Childrens Fund (UNICEF) and the World Health Organisation (2021) guidelines. As domestic water services costs in England and Wales are predominantly not volume linked, with a substantial fixed cost element, the impact on affordability is related to relative income levels (as discussed in Section 2.2.3).

- Is the provision of water and sanitation services financially secure and sustainable?

The financial security of water and sanitation provision, given that this is a public service, is of great importance. Financial security, and in particular public debt, has been the reasoning behind substantial changes in the way these services have been provided in the past (Beecher, 1997, Byatt, 2013) and once again is leading to public concern (BBC Panorama, 2023, Horton H., 2023, Water UK, 2021). Therefore, the security and sustainability of financing is critical to delivering the required service provision. Considerations such as public debt (Bălăcescu et al., 2022, Li et al., 2019a, Sironen et al., 2014) are critical at a regional and national scale but are not appropriate at the surface water system scale if services are provided through centralised routes; however, where direct procurement for customers is considered as a funding mechanism (Ofwat, 2024b) then these factors come into play once again.

- Are value generation opportunities across water and wastewater services optimised across the surface water system?

Finally, it is important to understand the value generation opportunities within the surface water system. The prevailing view of how value should be measured determines whether this becomes a measure of contribution to GDP, a calculation of alternative forms of value, or quantification of the proportion recovered. There is an opportunity within society for the formation of a circular economy through the generation of products and services from water and wastewater operations. Some of these mechanisms (such as sludge use in agriculture) are well established as can be observed from regulations supporting their use (Public Health England and Wales and Public Health Scotland, 1989) and the inclusion of these attributes within indicators (Hellstrom et al., 2000, Rogers et al., 2020, van Leeuwen et al., 2012). Additional recovery opportunities are yet to be realised, fully or at all, across the UK (Renfrew et al., 2022). The value derived from the generation of products is variable on a range of factors and may best be understood in economic terms; however the embedment of a circular economy within society and the potential for widespread benefits in employment and sustainability could be indicated through the proportion of water and wastewater that is subject to varying degrees of resource recovery.

4.4.2 Proposed indicators: initial view

Whilst there is a diverse array of indicators present within the literature many of these do not specifically target the objective of environmental justice. This is not to say that they are not valid forms of assessment - more that they, in this form, do not enable an assessment of environmental justice across the realms of environment, society and economy. It is proposed that two tiers of assessment take place, one at the regional or national scale to assess the overall nature of relationships with the surface water system and the other to make an assessment at the system and sub-system scale.

Indicators that are not possible to break down into system level datasets are positioned at the regional scale alongside datasets which are neither granular nor universal enough to act as a system level indicator. These include measurement of GDP and capitals, as well as wastewater-based epidemiology indicators which do not have universal coverage and for which the ethical implications of use at multiple scales is yet to be determined (Bowes et al., 2023, Robins et al., 2022). An understanding of debt level or investment-risk score (Bălăcescu et al., 2022, Li et al., 2019a, Sironen et al., 2014) would be beneficial in order to assess the viability of investment through current routes within a geographic area. An assessment against planetary boundaries as outlined by Raworth (2022) would provide a broader view of alignment to one-planet principles at the regional, country or global scales.

Due to the complex nature of the surface water system and the relationships within it there is a need to look beyond aggregated metrics to understand the nuances within an area if it is to be possible to understand the implications through a lens of environmental justice.

At the system, and subsystem scale, environmental indicators of environmental justice could be considered through ecological status, chemical status, renewable water and physical modifications of the surface water system. This would enable quantification of the main factors that were observed to influence the ability to thrive following system mapping and address areas such as ecological water levels that are not included within existing indicators. Similarly, consideration of societal indicators of environmental justice would incorporate potable water quality, public health risks through understanding environmental pathogen levels, human health index and distance from blue-green infrastructure. Finally economic indicators would focus on affordability through assessment of water price, relative income levels and resource recovery opportunities.

The use of recommended weighting systems to be applied across indicators, although prevalent within the literature (as discussed in Section 3.6.5) is not in line with an environmental justice-led approach. The introduction of weightings in the analysis allows opportunities for the introduction of bias, and the requirements of those without a strong voice to be lessened. Whilst localised prioritisation of needs should be encouraged, this should be achieved through open and transparent discussion of the characteristics, and therefore requirements, of the system and in cognisance of changing requirements into the future and for different users, both human and non-human.

4.4.3 Verification of the approach

4.4.3.1 Questionnaire responses

The environmental justice-led approach presented herein was tested with UK industry practitioners via a questionnaire and then through a series of semi-structured interviews as detailed in Section 3.6.4. The findings from this process have guided the final proposal of indicators as discussed in Section 4.4.5. Participants' experience spanned government organisations, water companies and environmental NGOs, with approximately half currently involved in partnerships. It should be noted that participants willingness to participate in the research and express views on decision-making may indicate a willingness to challenge the status quo and consequently be more critical of current systems and methods. The following is a summary of the main findings from the questionnaire and semi-structured interviews completed by industry experts.

Questionnaire responses that were expanded on in semi-structured interviews are included in Section 4.4.3.2 with responses included in full in Appendix D and the transcript of interviews included in full in Appendix E. Opinions on specific indicators to be used in assessments were obtained (Figures 4-23 to 4-25), broad agreement was observed across environmental and economic factors, however there was a wider range of responses for societal factors reflecting the diverse ways in which assessments could be made and where the boundary is drawn for the impacts of water system management on society. For example, level of education and employment were both raised as potential indicators, whilst there are links between engagement with the natural environment and educational outcomes (Dillon and Lovell, 2022) this is an indirect link only made possible through additional access measures. Similarly, the natural environment, including river systems, can impact employment and training opportunities, although this is facilitated through additional systems and mechanisms.

There was agreement from participants (Figure 4-23) that ecological status, chemical status and physical modification were highly relevant ecological indicators, a finding that is unsurprising as they constitute a major part of EA reporting of waterbody status (Environment Agency, 2023a). Renewable water was also viewed as highly important. Additionally, ‘land use’ was suggested to understand both water consumption and risk level for diffuse pollution, whilst ‘natural capital’ was suggested as a means to provide baselining.

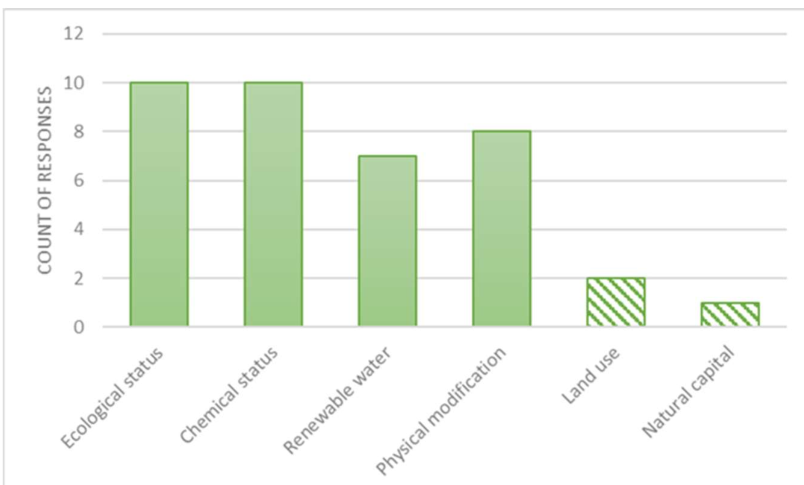


Figure 4-23: Questionnaire responses: Which of these, or additional, indicators would enable analysis of the catchment or sub-catchment from an environmental viewpoint? (Select all that apply). Patterned fill to a column indicates this was a suggestion from participant

There was strong consensus (Figure 4-24) that societal indicators should include a human health index, the impact of wastewater operations on public health (environmental pathogen levels), the distance to blue-green infrastructure and potable water quality. Additional suggestions reflected the broader societal value that the water environment supports: heritage, employment, education and flood management.

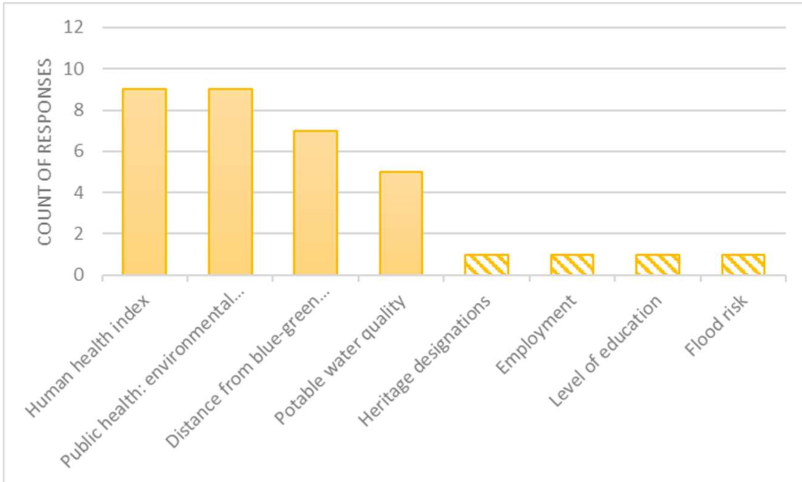


Figure 4-24: Questionnaire responses: Which of these, or additional, indicators would enable analysis of the catchment or sub-catchment from a societal viewpoint? (Select all that apply). Patterned fill to a column indicates this was a suggestion from participants

Responses regarding economic indicators (Figure 4-25) did not include suggestions in addition to the options indicated within the questionnaire. This may indicate that the suggested options were comprehensive as they included broad categories, although it may equally suggest that the respondents do not regularly consider the economic impacts of water systems or that their value is considered more closely linked to ecological or societal values.

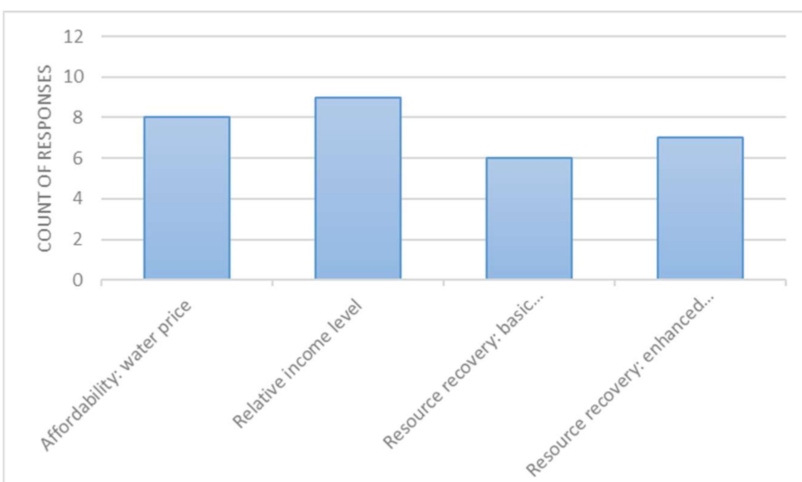


Figure 4-25: Questionnaire responses: Which of these, or additional, indicators would enable analysis of the catchment or sub-catchment from an economic viewpoint? (Select all that apply)

4.4.3.2 Analysis of semi-structured interviews

Understanding and communicating issues within a catchment

Across the realms of environmental, social and economic requirements participants felt these were poorly represented with some variation based on the requirement type (Figure 4-26). Consequently, this may mean that there is a preference to address some issues, regulatory driven environmental benefits, which may have unforeseen consequences across social and economic realms that lead to greater levels of social injustice.

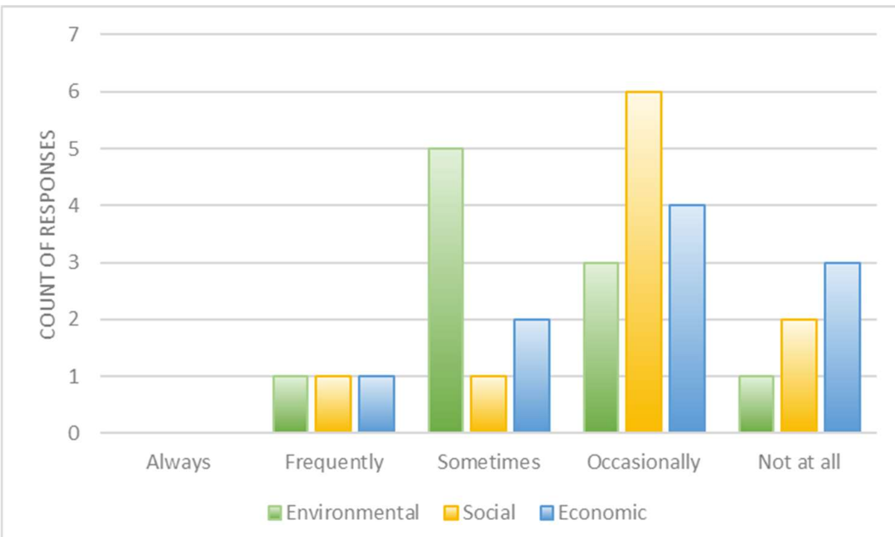


Figure 4-26: Questionnaire responses: Do you think that environmental/social/economic pressures across the catchment are well understood and communicated?

In-depth discussions raised the issue of boundaries, and how these interact with the communication of issues and corresponding action:

"So I think the problem we have is everybody just looks at it from their own perspective and in [the] *urban context is even harder because local authority boundaries tend to be much more respected if you like, than the natural boundaries of the catchment. … Which makes it really difficult to really think about what impact we want to see across all parties [and the] sort of*

risks that we need to think about now, especially with climate change and population growth… It's cultural as well, so it's so institutionalized and it's really difficult to breakthrough that."

The mechanisms currently in place to analyse, plan and initiate actions related to both the urban environment and the water system are oriented around administrative boundaries, be they local authority or a delineated waterbody. To enable inclusive discussion and exploration of issues at an appropriate scale a place-based approach is needed that incorporates multiple stakeholders and participants to overcome administrative barriers. However, these communities are not homogenous and therefore how requirements are represented becomes relevant:

"the needs of whom basically are we thinking about and how are we asking that particular audience what their needs are or just second guessing… And deprived communities, inner city communities, young people, old people, they're, I think, underrepresented in the environmental sector and they have to lump with action plans of the well-meaning branded as sustainability… that really don't deliver for that society."

This was echoed across multiple discussions and reflects the level of organisation present within an area both within communities themselves:

"An inverse relationship between the two [environmental harm and social justice] *in the sense that you know where you see the greatest activities and activism in terms of kind of catchment led approaches or for example, bathing waters in the Ilkley, it's led by generally you know relatively well-off people, well educated people who can organize themselves and have connections."*

Within catchment partnerships some of which are becoming highly organised and influential entities there remains a tendency to focus on environmental issues:

"Some [catchment partnerships] you know are a skeleton of an entity and actually some are getting quite mature and have some sophisticated models actually behind them in terms of bringing data and people being able to organize differently, bringing data together. Putting solutions in place, procuring solutions. So, I think that's probably quite a big spectrum in terms of the extent to which there's an understanding of the issues, the extent to which that's truly integrated with social and equity type issues. I think it's probably it's largely environmentally driven I think in that regard and probably scratching the surface on the social side."

A place-based multiple perspective approach is required that enables interrogation at multiple scales in order to extract information that will deliver appropriate outcomes across the whole of society. It is notable that within discussions there was concern over the level of societal representation. This may be reflective of the increased confidence that environmental needs were well understood, and the current climate of societal distrust in the water sector (BBC Panorama, 2023, Consumer Council for Water, 2021b, Consumer Council for Water, 2021a, Horton H., 2023, Water UK, 2021). However, there was an appreciation that the system as a whole is more complex than current assessments allow for:

"There're so many impacts and so many influences on the river, not just one …[but] *that understanding* [that an integrated approach is needed] *is completely lacking"*

Additionally:

"I'm not sure there's necessarily a huge amount of knowledge as to how the full system interacts and particularly how kind of that natural system interacts with the more man-made system."

This level of complexity and the lack of understanding causes further ramifications when there is societal or community appetite for action:

"when you're trying to do something to understand the catchments where it's going to take time, let's say a year or two of data gathering, sampling and understanding the catchment you just get called out for inaction and that you're not actually doing anything [but] *what you're trying to do is make sure the money goes in the right place and make sure the work gets done in the right way."*

Translation into action plans

Once needs, or requirements, have been identified these are translated into action plans, the action plans can take different forms (for example, (Northumbrian Water, 2023, United Utilities, 2023, Westcountry Rivers Trust, 2018). The issue of scale arises here again, what scale is most appropriate and how to manage this across varied administrative boundaries. This is considered to have a variable degree of success (Figure 4-27).

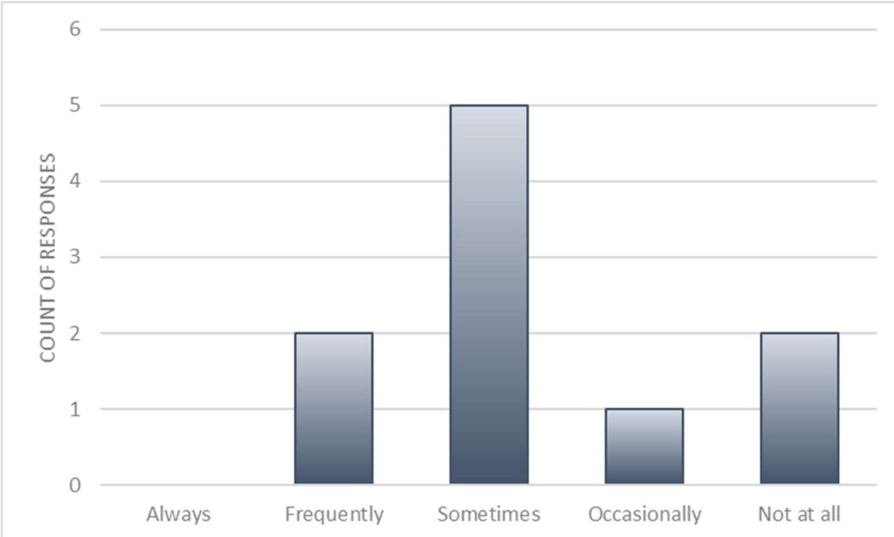


Figure 4-27: Questionnaire responses: How well do you think that identified issues are translated into action plans or interventions?

Statutory water quality objectives and the process of water company business plan development highlights the marginal role that society plays in this process:

"the guidance is made by the regulators, is imposed is delivered by the water companies and the customer pays for it, but has very little intervention or participation or collaboration in terms of what they are actually paying for."

Democratising the process enables both needs to be better communicated and expressed, but also provides transparency across this initial assessment, the development of plans and their delivery and ongoing management. This is borne out, perhaps unsurprisingly, in that the participants currently working within a partnership felt that this had a positive impact on their understanding of issues (Figure 4-28). Furthermore, without effective collaboration there is a breakdown in inclusion with consequential justice implications.

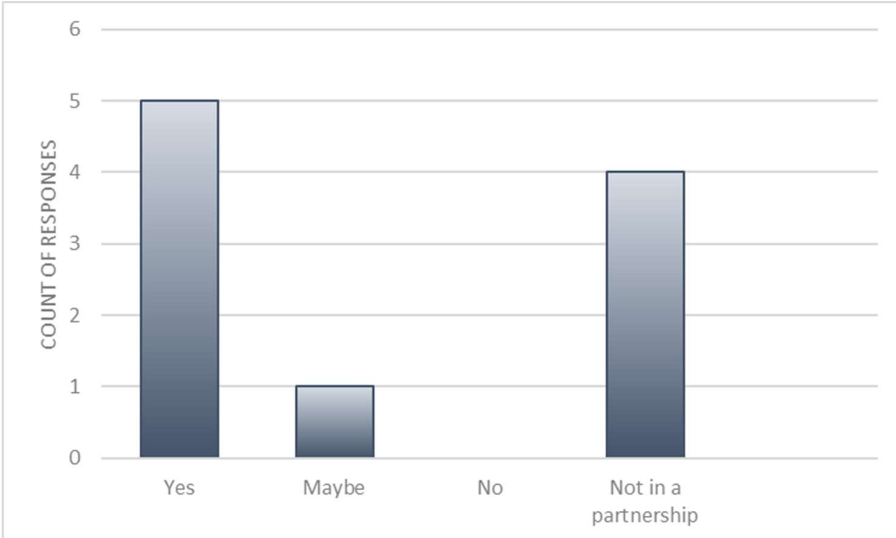


Figure 4-28: Questionnaire responses: Do you think your current partnership within this catchment (if you have one) has enabled greater communication and shared understanding of issues?

In addition to collaboration a systematic approach is needed which is both applied to systemic solutions, but importantly is used to develop and support collaborative management of the water environment:

"as a sector or as a country, or whichever way you want to look at this, there isn't systemic integration. Looking at the issue in this way and working through the issues and coming through to coming up with solutions and interventions that then get procured and funded, we don't have this. A systematic way of bringing these kind of ways of working and thinking and partnerships and collaborations into key decision making process doesn't exist."

The difficulties in expressing issues and translating them into action plans is further complicated by ownership and responsibility:

"that's a fundamental challenge because the system's pretty fractured in where the responsibility and ownership etcetera sits"

The fracturing of ownership and responsibility extends into how issues are raised, translated and discussed:

"So, from a catchment point of view, [instead of looking at] the multitude of issues that contribute to [an outcome, the focus is on] *one single entity within that catchment … and what we end up with is wasting money and not seeing the improvement that we all, or that everyone expected, to see by solving that one issue…* [There is a] *lack of desire to look at root causes rather than, you know, just looking at what the outcome of those root causes are."*

As well as how they are regulated:

"any action has to be able to be regulated in the way that regulation works, as opposed to [determining] this is what needs to happen, so, let's think of a way we can regulate that"

Therefore, for action plans to be effective, and to represent the requirements of a specific area, they need to be accompanied by a collaborative and regulatory framework that is supportive. This is counter to established views that the regulator is positioned outside collaboration so as not to be accused of being 'soft on regulation'.

Planning for the future

Plans made now will need to continue to function for many years and decades into the future, however this is not matched by views of planning timescales within the sector (Figure 4-29).

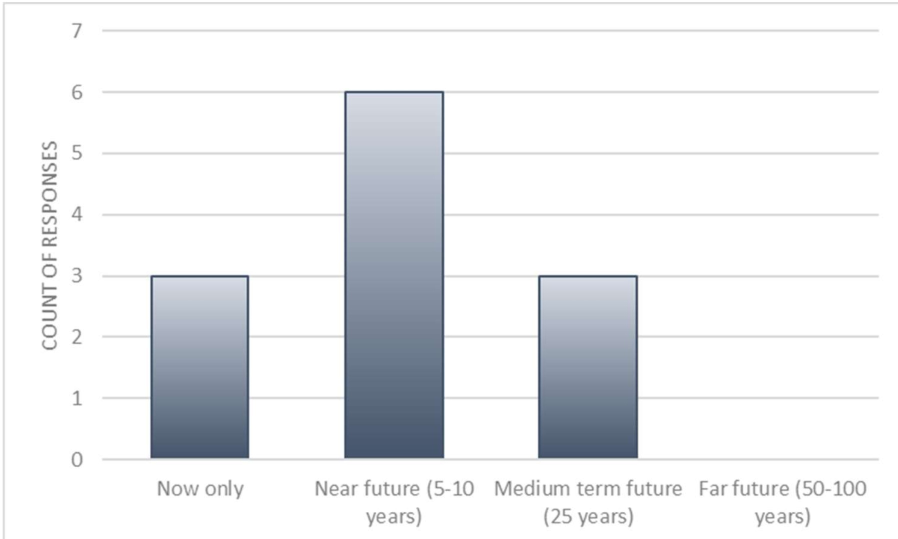


Figure 4-29: Questionnaire responses: Do current needs assessments focus on the now, or do they look into future requirements? (Select all that apply)

This timeframe reflects the industry requirement to incorporate 25-year environment plan (UK Government, 2018) within the WINEP and water company business plans, however:

"They're [the 25-year plans are] *non-statutory… So it's not important - not to the regulator who designed them, and not to the water companies - because delivering non-statutory requirements is a nice to have"*

Within a regulated industry that is incentivised only on the delivery of regulatory requirements, having 25-year plan inclusions which are non-statutory devalues this process does not embed long-term thinking and undermines the universality of implementation. However, it was also noted that:

"[There is] a limit to what you're gonna hang off any individual piece of legislation, though it's a big one, an important one, it's probably a bit too outputs focused in some ways"

This is compounded by a view that:

"regulation alone isn't enough… we're not gonna hit all of our environmental targets just through regulation."

There has been a tendency towards short-termism which is impacting the ability to meet current requirements and respond to emerging needs:

"The short termism is the worst thing… the 20th century [ethos] *was keep going faster, keep going shorter, keep doing it quicker... It's the century that defined short termism, and we're still stuck in it."*

Whilst this is the case for wastewater, the planning process within water supply is more proactive:

"We plan for water resources, we try to at least… Whereas both with flood risk management and water quality, it's reactive… I think that the habits of water resources in terms of being forward looking are the things that we need to adopt very widely"

"on the water resource side. We are in the place of really managing risk, whereas on the order of wastewater, we're really surrounded by issues"

Outside the regulated water industry, within NGOs, reference to the 25-year environment plan was notable by its absence:

"I don't ever think about it…. quite honestly, you know, I know it's out there somewhere, and occasionally it raises his head where perhaps we've got a funding opportunity. And then maybe we'll look to see how we meet that through the environment plan, etcetera"

However, there was also a frustration with short-termism:

“we're probably more frustrated by, you know, governments and short term views… wouldn't it be great if we all had a plan that did what you say in and looked, you know, at least 50 years into the future like forestry does.”

The difference in approach here is notable in that a long-term planning process is accepted within forestry due to the timescales of tree growth. However, within the water environment, and particularly lakes, there is a decades-long time-lag between reducing inputs and achieving water quality and biodiversity outcomes due to the equilibrium between sediments and the water column (Rippey et al., 2021). However, this is not outwardly recognised, possibly linked to the events being at a microscopic or molecular level rather than in the visible realm. This reflects a need to utilise visualisations to facilitate systemic solutions (Section 4.1.2).

Aspirational priorities

It is expected that as time progresses priorities will change and adapt, this may be due to several factors including relative position on Maslow’s hierarchy of needs, changing demographics and cultural shifts or external pressures. Participants views of aspirations (Figure 4-30) broadly reflect the language held within regulatory documents (Section 2.1).

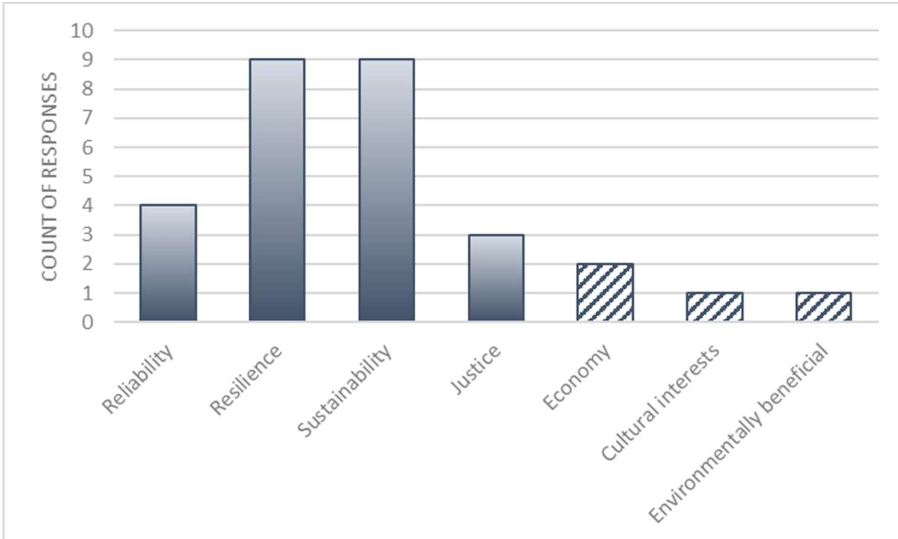


Figure 4-30: Questionnaire responses. What level of aspiration for the catchment do you think is most appropriate? (Select all that apply). Pattern fill to column indicates this was a suggestion from participant

Some participants highlighted the nuance that is required in defining requirements and priorities, this was expanded upon in discussions:

"The outcomes we want to achieve...will be dictated by geography...actually things are varied according to the geography and people tend to talk about value when what they mean is price... but price follows value and value follows experience and also context... Most of the time, all of the layers of [Maslow's] hierarchy are always relevant, even when one of them dominates."

Value was seen as a critical aspect across participants, and in particular the lack of value placed on the water environment:

"I think there's an element too of how you get people to value the water environment, you know, to respect it, to recognize their impact on it, to daily life and the fact that we can flush the toilet and not ever think again about what we put down. It is a very, very privileged position to be in."

Considering the level of aspiration across the water sector, although specifically within the water industry as it is the largest route for investment:

"I think concentration on resilience has an economic basis to it, as in it's a protection of profitability, not necessarily for the benefit of wider society."

Moreover,

"There is a lot of stuff being done around resilience and I do think that is correct, but I also do think that we need to look at the justness and the fairness"

When asked about the inclusion of justice approaches in water company planning, there is a view that this is an unconscious undercurrent to conversations:

"Certainly [there is] *some thought process that goes into how you can drive more of that kind of social justice point, rather than necessarily being directly baked into how we do those assessments"*

But this is countered by the operating principles set out through regulation:

"[water companies' are] really driven by efficiency as being our core metric. That efficiency almost has baked-in social injustice in it, in the sense that driving to the lowest overall cost across the whole region. Where infrastructure gets directed, at where you're putting things and fundamentally when you're trying to just deliver a broad efficiency envelope, then that leads you to make certain decisions that just exacerbate societal challenges… it's always going to be cheaper to buy land and dig a big hole in a poor part of the world than it is to go park your diggers up on the front of Buckingham Palace"

This sums up a fundamental legacy justice issue in that wastewater infrastructure is predominantly placed in industrial and less-affluent areas. The air quality impacts, environmental impacts and industrial landscape this generates continues to de-value land in these areas making them more cost efficient for future infrastructure development increasing the impacts to local communities and increasing levels of social injustice.

The conversations progressed into discussions of cultural values, trust, social learning and risk, emphasising the human element in experience of the water system and therefore the definition of requirements by communities:

"cultural values can make or break decisions... is this solution and the residual risk and the tolerability [acceptable]*... there's a social learning part of this... Trust is absolutely critical to making this whole thing work"*

Since privatisation, water companies have had a duty to provide water services across society as a public good. This has been provided as a 'silent service', however recent events have raised questions over the capabilities of water companies and a lack of transparency in both the services they deliver and events which may disrupt these services has broken this trust relationship:

"The public and water companies are at odds... They don't trust each other, and this is having a ripple effect on investors, markets, politicians and others... You need those that can come in as third parties who don't have skin in the game and can start to rebuild those bridges... third party mediation role, but also not just mediating, but scrutinizing, providing independency and making sure they're not representing anybody... Not representing anybody means you're

representing everybody and more importantly to be able to take that data and make it into accessible information"

There is growing mistrust in the providers of information leading to an increasing need for independence in the provision of information to wider society:

"[For example a study] that's been commissioned by the Environment Agency and immediately [people] disregard it because they think they're in cahoots. "

Therefore, the requirements of water systems are varied, they vary by geography, but also by cultural values. The current paradigm of water services being provided to society is no longer acceptable and a new paradigm is required which involves the open and transparent sharing of information to not only guide the targets, but also the means of delivering these targets. This is a shift to a justice-led approach that requires co-operation between all parties related to the surface water system, and supportive tools to facilitate it.

Visualisations

This leads to a discussion on visualisation; visualisations are a way of representing information to lead to knowledge. This information is fed by data, however the data itself is typically only understood by certain audiences, the value of providing visualisations comes from the ability to translate data into a form in which it becomes information and knowledge to a wide range of actors who may have different preferences, as did participants (Figure 4-31).

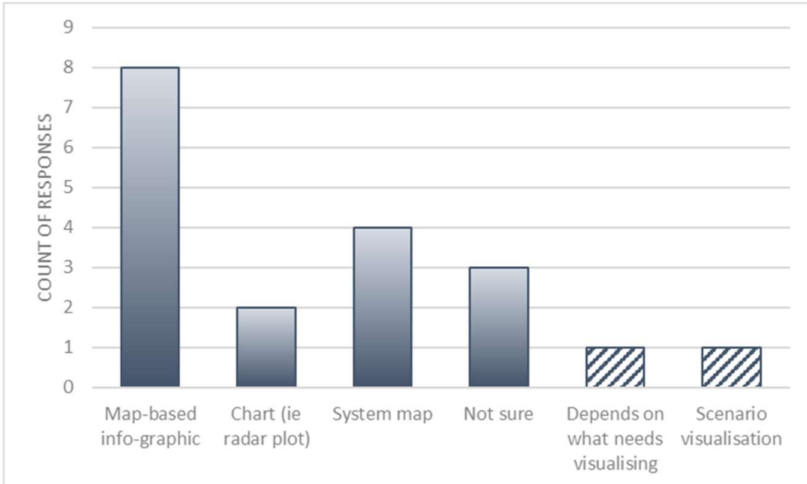


Figure 4-31: Questionnaire responses: What level of visualisation would enable best use to be made of outputs? (Select all that apply). Pattern fill to column indicates this was a suggestion from participant

An example of visualisations effectively conveying data to provide information to a wide audience that has then fostered collective action and targeted investment is The Rivers Trust Sewage Map (The Rivers Trust, 2024b). This gave transparency to the frequency and scale of combined sewer overflow (CSO) spills drawing this issue into the public eye:

"[the sewage map] *kicked off the whole movement around CSOs because suddenly information was explained. It was humanized"*

By translating data into a format that was readily accessible it created transparency and enabled communities and society to demand action is taken. This has highlighted the water environment in the public psyche; however, it has also reduced trust. Now public collaboration, input and scrutiny of the actions taken to remedy the problem is required:

"We need to make the solutions accessible to the people who made all of this noise, the same way that The Rivers Trust 'Sewage Map' made the problem accessible to all. There's got to be scrutiny, [and this] *needs to sit outside of government outside of political boundaries."*

Communities become more engaged when the information relates to their local area:

"If it's tailored and it's pertinent to what they do, how they work on their business and well, their quality of life, any of those sorts of things, then I think that's really where we can get a lot sharper."

The Sewage Map, however, represents one influence of the water system, CSO discharges, and society's interaction with water. The system is more complex as made apparent in the system maps developed in Section 4.1 and evident in geographical variability of impacts.

Data alone is not able to re-build trust, although it is part of the approach that is needed. Collaborative action will build trust, and data is one of the mechanisms to facilitate this:

"I think it's an inherently a very good idea to kind of use multiple data sources… how much will that really move the dial on the trust side? I don't know, you know because, I think it's a good idea. I just don't know how much I see that as being part of the trust picture, although for sure it's there's a link there I think trust ultimately gets established most when there's collaboration… if [water industry investment] can then be invested in a way that brings the communities into the decision making processes and actually into the actions on the ground, including through multiple levels of sources of data that I think can help build trust."

Therefore, critical to delivering system-wide solutions and improvements is collaboration which extends beyond institutional boundaries and involves communities in their entirety. Visualisations and analysis of multiple data sources are tools that can be used in this process to enable communication, re-build trust and elicit meaningful action based on knowledge.

4.4.3.3 Outcomes of validation

The questionnaires and semi-structured interviews have provided a richness of context within industry experts and practitioners. This has provided confidence that there is a recognition that justice-based tools would support the sector to overcome shortfalls in existing processes particularly through enabling the communication and investigation of complex systems. Furthermore, this has the potential to align with the Sewage Map to generate an accessible tool which reflects complexity within the system facilitating discussions and interventions to look beyond events to address route-causes.

Combined with system maps and causal loop diagrams this could form the basis of tools to support regulatory reform to include a more collaborative and justice-led approach for which there is cross-sector support.

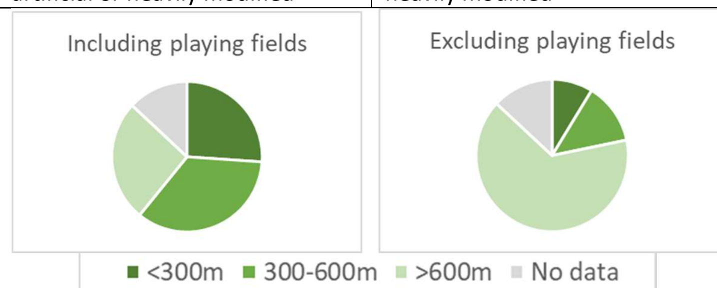
4.4.4 Cross-cutting analysis of two catchments in North-West England

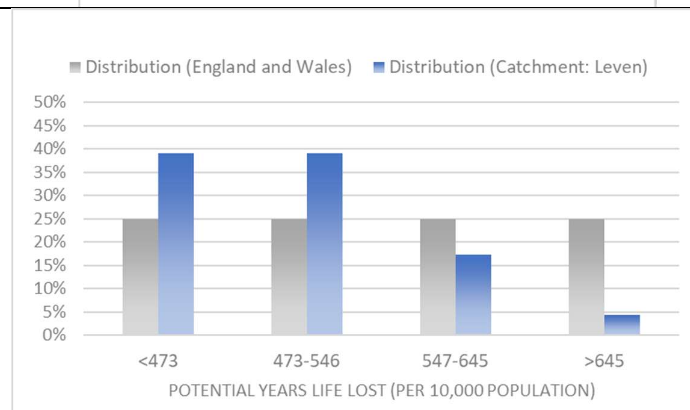
Investigations of two operational catchments and one waterbody to assess the level of data available has drawn together environmental data for a geographic area with comparative social data at the Lower Super Output Area (LSOA) level.

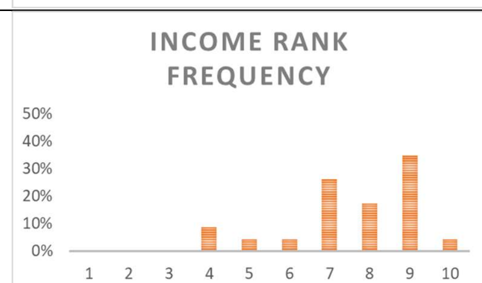
4.4.4.1 Leven operational catchment

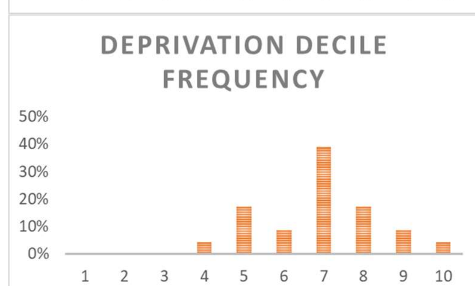
The Leven catchment in the South Lakes encompasses a number of tributaries, lakes and urban areas. Water quality parameters across this catchment are variable (Table 4-6) and the direct impacts across communities are unlikely to be homogenous. Although the majority of rivers are classified as of good ecological status this does not translate into the lakes, potentially due to the time lag between improving inputs to a lake and resultant changes in water quality within the lake itself (Rippey et al., 2021) or due to specific detrimental actions which directly impact lakes rather than the surrounding rivers, becks and streams. This is significant for the area due to the importance of the lakes, particularly Windermere, on local tourism (Bramwell and Pomfret, 2007).

Table 4-6: Leven: overview of a number of parameters across the catchment area

<table>
<tr><td colspan="2">Parameters</td><td colspan="4">Summary of the data</td></tr>
<tr><td rowspan="5">Ecological status (Environment Agency, 2023a)</td><td rowspan="2"></td><td colspan="2">Rivers</td><td colspan="2">Lakes</td></tr>
<tr><td>Number</td><td>Length</td><td>Number</td><td>Surface area</td></tr>
<tr><td>‘good’</td><td>11</td><td>82%</td><td>2</td><td>1%</td></tr>
<tr><td>‘moderate’</td><td>1</td><td>6%</td><td>8</td><td>99%</td></tr>
<tr><td>Worse than ‘moderate’</td><td>1</td><td>12%</td><td>0</td><td>0%</td></tr>
<tr><td colspan="2">Level of modification (Environment Agency, 2023a)</td><td colspan="2">All rivers designated as not artificial or heavily modified</td><td colspan="2">88% of lakes designated as heavily modified</td></tr>
<tr><td colspan="2">Access to public green space (data from (Office for National Statistics, 2020)).
Percentage of LSOAs with average distance from residence to green space within each category.</td><td colspan="4">


</td></tr>
<tr><td colspan="2">Health of the population (UK Government, 2019)
Potential years life lost (PYLL) data for each LSOA, distribution compared to overall distribution across England and Wales.
Grey bars represent an equal distribution between quartiles, blue bars show distribution within selected LSOAs. Lower PYLL relates to a lower potential years life lost and therefore a longer life.</td><td colspan="4">


</td></tr>
<tr><td colspan="2">Income distribution (UK Government, 2019)
Percentage of LSOAs within each decile of national statistics where 1 is lowest level of income and highest level of deprivation.</td><td colspan="4">




</td></tr>
</table>

The impact of public green space on public health is well understood (Konijnendijk, 2023, Public Health England, 2020, World Health Organization Regional Office for Europe, 2017), whereas the impact of blue spaces on public health has not been investigated to the same degree (Hunter et al., 2023). Despite this there is an association between urban green spaces and water quality (Liu et al., 2023) and green and blue spaces frequently interact, therefore assessment of the distance from homes to public green space can be used to provide an indication of the living environment within a locality. Lower Super Output Areas (LSOAs) have been used as the spatial data level at which analysis can be meaningfully conducted.

Across the Leven catchment there is wide variability in accessibility, with a relatively even distribution from less than 300m to over 600m when playing fields are included. These distances are significant as they relate to a 5- or 10-minute walk (respectively) ensuring proximity between residents and urban green space (Konijnendijk, 2023, Public Health England, 2020, World Health Organization Regional Office for Europe, 2017). However, this means that in some areas residents have to walk for more than 10 minutes to reach public green space. Notably there are three LSOAs for which no assessment has been made as the assessment is limited to built-up areas such as towns and cities (Office for National Statistics, 2020). Additionally, playing fields may be private and when these are excluded from the assessment the level of access substantially decreases.

The majority of populations across the Leven catchment have a life expectancy, measured as potential years life lost, that is skewed to the higher end of the national distribution indicating that the population has either comparable, or better health outcomes compared to the rest of the population in England. Similarly, the population is skewed to higher rankings of both income levels and deprivation rankings (where 1 is most deprived and lowest income) reflecting the economic status of the generalised population within the area. Notably the distribution of populations varies across the index of multiple deprivation and income rankings reflecting the contribution of additional factors including education, crime, employment, health and the living environment (UK Government, 2019) to overall outcomes.

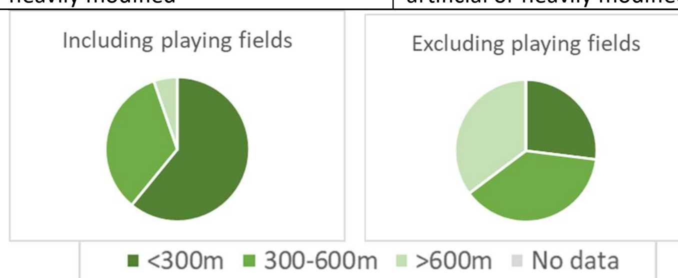
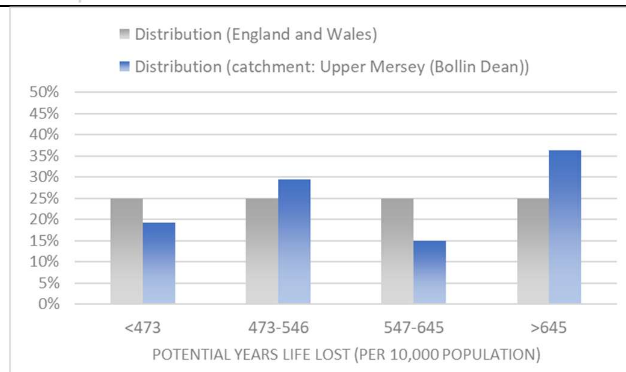
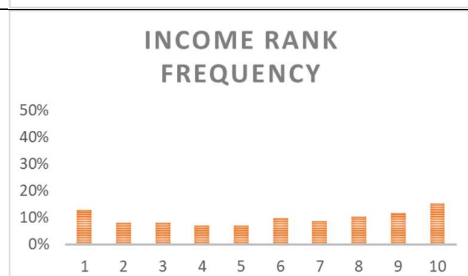
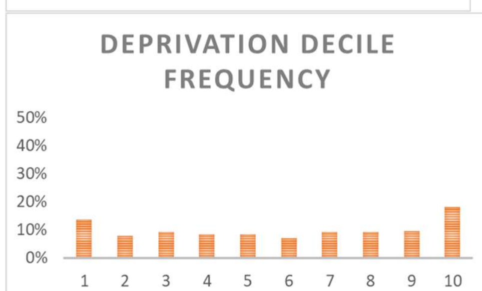
4.4.4.2 Upper Mersey (Bollin and Dean) operational catchment

The Mersey is a large river originating east of Manchester and Stockport; it traverses agricultural, industrial and urban areas before reaching the Irish Sea. Due to its large and complex nature the river is sub-divided into two management catchments and 6 operational catchments. Within each of these operational catchments are a number of waterbodies. This analysis will focus on one of these operational catchments: Upper Mersey (Bollin and Dean). Analysis of the operational catchment as a single entity (Table 4-7) shows an averaged position over variable geographies, functionalities and urban forms.

In comparison to the Leven, the Upper Mersey (Bollin and Dean) can be observed to have a water environment that is of a more degraded condition reflecting this as an urbanised environment with substantial industrial heritage. There is improved proximity to green space compared to the Leven, although when playing fields are excluded there is still a substantial proportion of the population which is more than 600 metres from public green space.

The Upper Mersey (Bollin and Dean) has a life expectancy, measured as PYLL, which is comparative or worse than the national average with no distinct trend. Similarly, the income distribution is reasonably evenly distributed between deciles indicating that there are a range of deprivation levels within this area.

Table 4-7: Upper Mersey (Bollin Dean): overview of a number of parameters across the catchment area

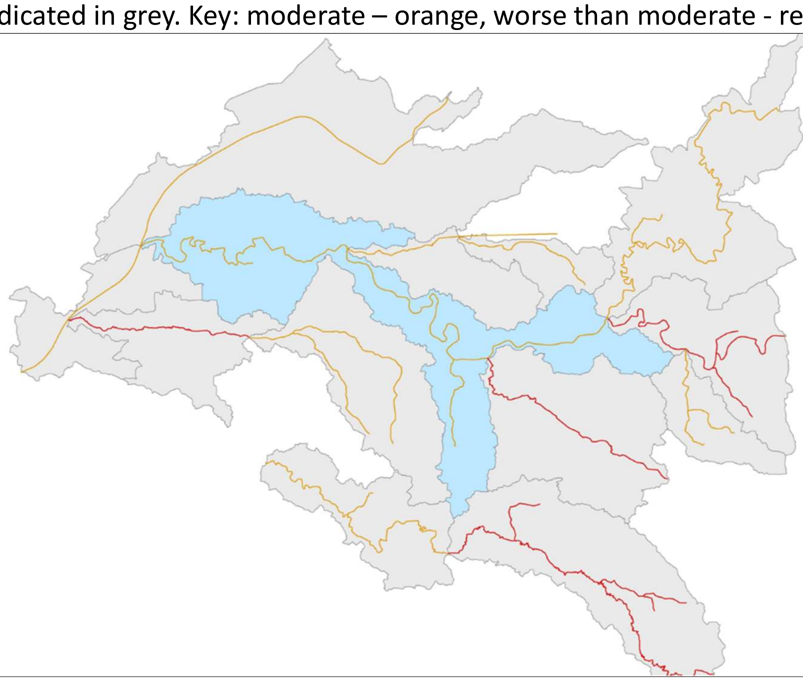
Parameters		Summary of the data			
Ecological status(Environment Agency, 2023a)		**Rivers**		**Lakes**	
		Number	Length	Number	Surface area
	'good'	0	0	0	0
	'moderate'	16	72%	10	48%
	Worse than 'moderate'	5	28%	2	52%
Level of modification (Environment Agency, 2023a)		48% of rivers heavily modified and 52% not designated artificial or heavily modified		69% of lakes heavily modified and 31% not designated artificial or heavily modified	
Access to public green space (data from (Office for National Statistics, 2020)). Percentage of LSOAs with average distance from residence to green space within each category.					
Health of the population (UK Government, 2019) Potential years life lost (PYLL) data for each LSOA, distribution compared to overall distribution across England and Wales. Grey bars represent an equal distribution between quartiles, blue bars show distribution within selected LSOAs. Lower PYLL relates to a lower potential years life lost and therefore a longer life.					
Income distribution (UK Government, 2019) Percentage of LSOAs within each decile of national statistics where 1 is lowest level of income and highest level of deprivation.					

4.4.4.3 Single waterbody: Upper Mersey (upstream of Manchester Ship Canal (MSC))

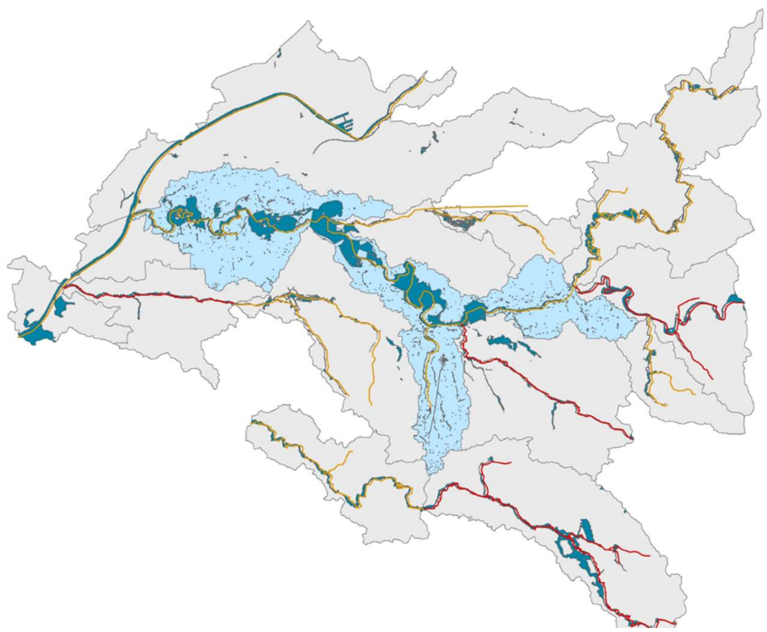
A more detailed analysis of these parameters across a single waterbody (Table 4-8) starts to break down this nuance into a scale at which information and knowledge can start to be gained from the data. This has been carried out for a single waterbody to act as an exemplar of the granularity of available data, the level of variation which may be observed and ways in which this may be assessed.

Overlaying various data inputs with geographical information allows greater interrogation of the data and the ability to start to generate hypotheses over root causes. Areas within the waterbody catchment have been designated based on knowledge of the region; each area is indicated with a label and all LSOAs within the Mersey upstream of MSC waterbody are incorporated into one of the areas.

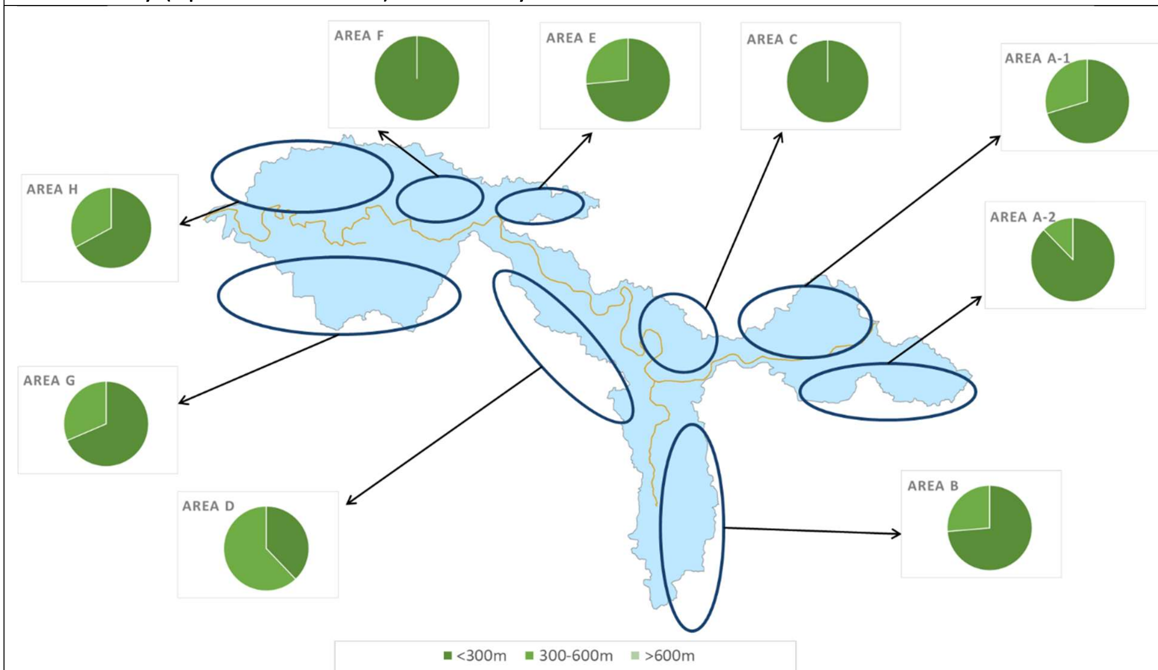
Table 4-8: Upper Mersey: analysis of the Mersey (upstream of MSC) waterbody

Ecological status Mersey (upstream of MSC) waterbody highlighted in blue, with surrounding waterbodies indicated in grey. Key: moderate – orange, worse than moderate - red


Flood risk
Fluvial flood risk (1% or greater) for all waterbodies (blue) and pluvial flood risk (3.3%) shown for Mersey (upstream of MSC) waterbody only. Superimposed onto catchment map

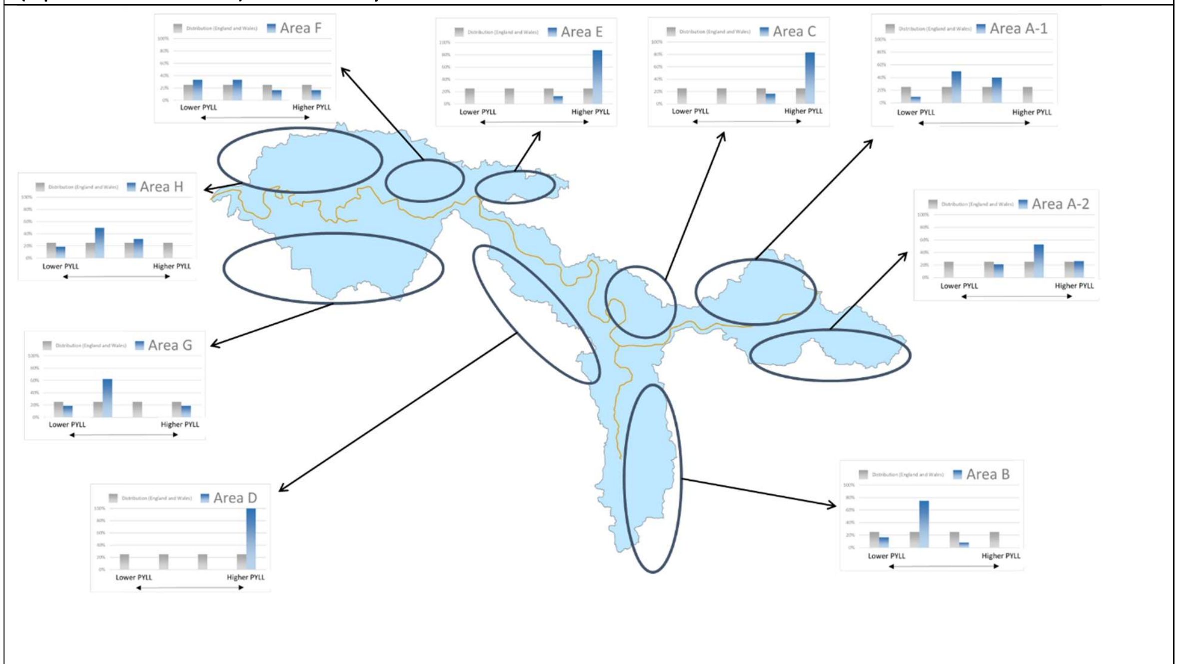


Access to green space
Distance to public green spaces (including playing fields) for different residential areas within the Mersey (upstream of MSC) waterbody



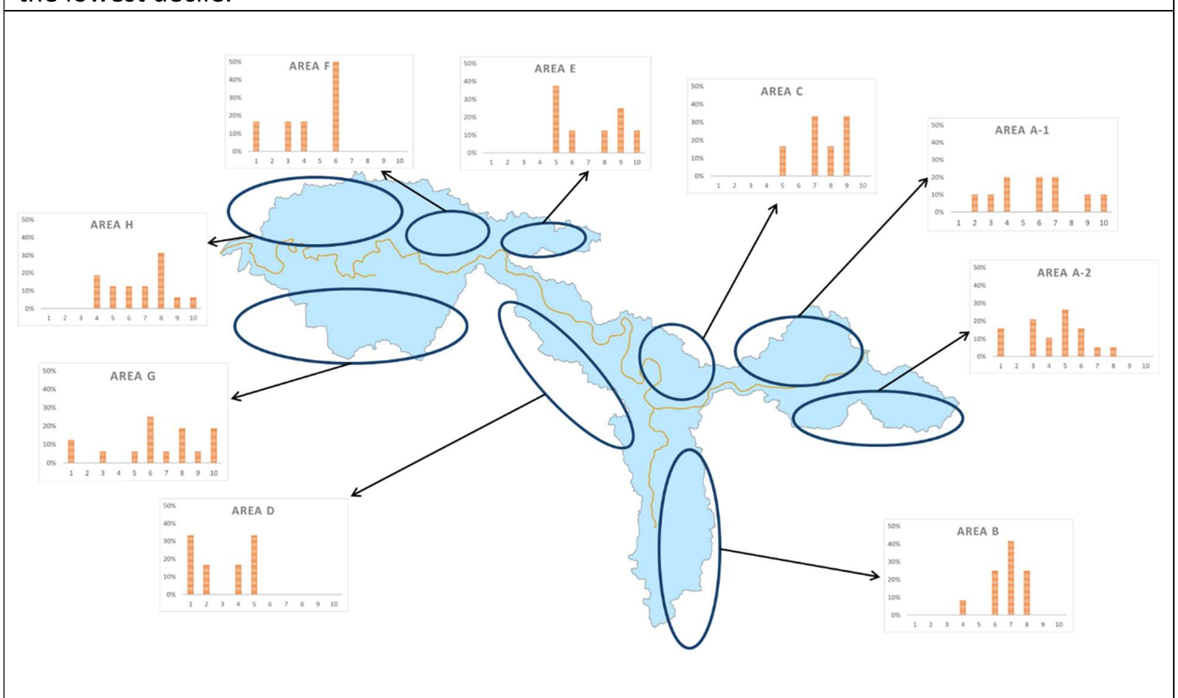
Human health

Comparison of potential years life lost within different residential areas within the Mersey (upstream of MSC) waterbody



Income distribution

Comparison of income distribution within different residential areas within the Mersey (upstream of MSC) waterbody. Charts show percentage of LSOAs within each decile where 1 is the lowest decile.



Overall, within this waterbody the distance to green space is low, aided by the legacy of Victorian parks in much of the area and publicly accessible land surrounding the River Mersey which acts as flood protection for much of South Manchester. Area B is one of the more affluent parts of the waterbody and of the country - this is accompanied by a lower potential years life lost (PYLL) measure and shorter distances to public green space however within this area there is a cluster of pluvial flood risk which could be connected to the increased distance from the main course of the River Mersey. Contrastingly the neighbouring Area D is one of the least affluent with a higher PYLL and longer distance between residential areas and public green space. Area A has been split in the analysis into the region above the river and the region below it since there is a difference in income distribution between these areas, slight variation in distance to green space, and substantial differences in health outcomes (measured as PYLL). This is accompanied by a variation in the ecological status of the surrounding waterbodies, of which two are classified as 'poor' surrounding Area A-1 whilst the remainder of waterbodies are classified as 'moderate'.

Side-by-side comparison of these metrics adds nuance to the interpretation of living conditions and environmental conditions experienced within defined areas. However, completing this assessment involves matching disparate data sets that are collected in variable timeframes meaning they are subject to different judicial boundaries. This degree of processing reduces the accessibility of information, additionally some factors remain absent from these assessments as does a universal understanding of what is 'good'.

4.4.5 Proposal of indicators at the surface water system scale

4.4.5.1 Overview

An environmental justice-led approach to reviewing existing indicators, the objectives of indicators and applying the outputs of the validation questionnaire and follow-up discussions, alongside analysis of some of the currently available data, has led to the definition of specific indicators and benchmarks. The proposed indicators represent a starting point for cross-cutting analysis based on the data available at an appropriate scale to enable meaningful analysis. It is proposed that these are visualised at the system and sub-system scale to enable meaningful and accessible information. The proposed colours have been chosen to enable colour blind accessibility.

Additionally, due to the potential impact of fragmented or unrepresentative data, there is a need to incorporate additional measures to build trust in the assessment. The adoption of a confidence score, or healthcheck, of the indicator, using various information sources, would provide insights of where data does not reflect the received knowledge. These insights improve transparency and enable the improvement of datasets and knowledge to facilitate effective action. The goal of this exercise is to increase the level of trust in the information presented, and to highlight where there are gaps in data measurements which may have an influence on actions that are subsequently undertaken. These indicators are discussed in more detail in the following section.

4.4.5.2 Environmental indicators

The purpose of environmental indicators is to evaluate whether the conditions are supportive to a thriving ecology. It is proposed that assessment of ecological and chemical status alongside wider impacts and physical modification would provide this overview.

ENV1 – Ecological status An assessment using nationally-available ecological classifications cross-checked against local knowledge and specific data sources (Table 4-9).

Table 4-9: ENV1 - Ecological status. Details of proposed indicator

Metric	**Ecological status:** Percentage km/km Calculate % 'good' and % 'moderate' across system or sub-system.		
Benchmark	Water Framework Directive (WFD) target is for all rivers to achieve good ecological status (Directive 2000/60/EC, 2000)		
Benchmark visualisation	Target	Satisfactory	Inadequate
	100% 'good' classification	Not 100% 'good' and less than 25% 'worse than moderate'	More than 25% 'worse than moderate'
'Healthcheck'	Cross-check with additional evidence sources such as citizen science data		

Ecological status is the WFD driven assessment of alignment with a near natural state, or with the potential to be near-natural. This data can be assessed at multiple scales providing national, regional, operational catchment and waterbody levels of granularity. This may be further supported by the Natural Capital and Ecosystems Assessment (UK Government, 2022a) and Catchment Monitoring Cooperative (The Rivers Trust, 2021) as these initiatives come into effect, thereby providing robust and nationally comparable data that can build trust in the assessment.

ENV2 – Chemical status An assessment using nationally available chemical classifications cross-checked against local knowledge and specific data sources (Table 4-10).

Table 4-10: ENV2 – Chemical status. Details of proposed indicator

Metric	**Chemical status:** Percentage km/km Calculate % 'good' across system or sub-system.		
Benchmark	WFD target is for all rivers to achieve good chemical status (Directive 2000/60/EC, 2000)		
Benchmark visualisation	Target	Satisfactory	Inadequate
	100% 'good' classification	More than 50% 'good' classification	Less than 50% 'good' classification
'Healthcheck'	Cross-check with additional evidence sources such as citizen science data		

Across England there are no water bodies that have 'good' chemical status (Environment Agency, 2023b). This relates to the addition of a number of chemical species into the assessment that were previously unknown, if these species are excluded then 93% are at 'good' status. This reflects the current status of the water industry as 'playing catch-up' to the emerging science around the prevalence of these contaminants, the risk they pose and the development of treatment methods for their removal (Brammer et al., 2018). Nevertheless, measurement of this data is vital to understanding the impact of human activity on water quality.

ENV3 – Wider environmental impact An assessment of the impact of water infrastructure on air and greenhouse gas emissions, cross-checked against local knowledge and specific data sources (Table 4-11).

Table 4-11: ENV3 – Wider environmental impact. Details of proposed indicator

Metric	**Wider environmental impact:** Assessment of greenhouse gas emissions associated with water infrastructure in the locality		
Benchmark	Achieving net zero (Water UK, 2020)		
Benchmark visualisation	Target	Satisfactory	Inadequate
	Net zero achieved	On track to achieve net zero by 2030	Not on track to achieve net zero by 2030
'Healthcheck'	Cross-check with local experiences on air quality		

Water infrastructure contributes to environmental impacts beyond the surface water environment, in particular it is associated with greenhouse gas emissions and directly contributes to national emissions (Chisholm, 2013). There is an industry roadmap to reach net zero by 2030 (Water UK, 2020), however there are concerns over whether this can be measured and calculated accurately (Black et al., 2023) and whether it is achievable (Black and Thompson, 2023). This metric proposes using water company recorded data to provide an overall view of progress towards net zero.

ENV4 – Physical modification An assessment using nationally-available classifications cross-checked against local knowledge (Table 4-12).

Table 4-12: ENV4 – Physical modification. Details of proposed indicator

Metric	**Physical modification:** Percentage km/km Stretch of classified as not artificial or heavily modified as percentage of complete length.		
Benchmark	No waterbody classified as artificial or heavily modified		
Benchmark visualisation	Target	Satisfactory	Inadequate
	100% 'not designated as artificial or heavily modified'	More than 50% 'not designated as artificial or heavily modified'	Less than 50% 'not designated as artificial or heavily modified'
'Healthcheck'	Comparison with local knowledge and the impact of modification on fragmenting or damaging the surface water environment		

Many water bodies across England are modified, and as such are classified as either artificial or heavily modified. The high level of modification, over 40% of waterbodies in England are classed as artificial or heavily modified (Environment Agency, 2019), stems from the heritage of areas. As such urban, agricultural and industrial development within the UK impacted the ability to provide sufficient habitats (UK Government, 2021b) with local action underway to restore functional habitats. Rivers and lakes are classified separately within the Environment Agency assessments (Environment Agency, 2023a). Typically lakes are more likely to be either artificial or heavily modified; in this assessment, the modification status is assessed only for rivers. This is due to the higher impact of river modification leading to the fragmentation of habitats (Seliger and Zeiringer, 2018) and reflects the current efforts to remove these barriers (The Rivers Trust, 2024a).

4.4.5.3 Societal indicators

The purpose of societal indicators is to evaluate whether the conditions are supportive to a thriving society, supporting the provision of water services and a healthy environment. It is proposed that assessment of levels of service provision, health outcomes and proximity to green spaces would provide this overview.

SOC1 – Potable water of sufficient quality An assessment using nationally-available assessments cross-checked against local knowledge and experience (Table 4-13).

Table 4-13: SOC1 – Potable water supply. Details of proposed indicator

Metric	**Potable water of sufficient quality:** Percentage of time meeting minimum standard		
Benchmark	Meeting minimum standard (UK Government, 2016)		
Benchmark visualisation	Target	Satisfactory	Inadequate
	100% of the time	>98% of the time	<98% of the time
'Healthcheck'	Cross-check with additional risk indicators		

Society expects the reliable provision of safe, drinking water in alignment with the statutory duty of water companies and the provision of this human right (United Nations, 2015). Within England 99% of the population receives its supply from a water company (Department for Environment Food & Rural Affairs, 2021a) and compliance with standards was 99.97% in 2022 (Drinking Water Inspectorate, 2022). The Drinking Water Inspectorate (DWI) generate a compliance risk index for each company based on the location and severity of a breach of standards, providing a robust assessment of risks for centralised supplies. However, other risk factors remain, such as private water supplies and lead piping in water supply pipes. An assessment of these risk factors is recommended to accompany an assessment of water service standards and reliability.

SOC2 – Environmental pathogen levels An assessment of environmental pathogen levels where this data is available, cross-checked against local knowledge, specific data sources and expected risk level relating to degradation pathways and timescales (Table 4-14).

Table 4-14: SOC2 – Environmental pathogens. Details of proposed indicator

Metric	**Environmental pathogen levels:** Assessment of whether environmental pathogen level within acceptable limits for public health measured in colony forming units (cfu).		
Benchmark	Pathogen levels compared with standards for recreation in inland waters (The Bathing Water Regulations, 2013)		
Benchmark visualisation	Target	Satisfactory	Inadequate
	E.coli <1,000cfu/100ml and Intestinal enterococci <400cfu/100ml (95%ile)	E.coli <900cfu/100ml and Intestinal enterococci <330cfu/100ml (90%ile)	Higher values of colony forming units (cfu) identified
'Healthcheck'	Cross-check with additional evidence sources (i.e. local recreational value of surface waters and local confidence levels)		

Measurement and assessment of the presence of pathogens within inland waterbodies is not prevalent across England (Environment Agency, 2024); however, this was noted as a high priority by questionnaire respondents (Section 4.4.3, Figure 4-24, page 164 and Appendix D). When combined with eDNA profiling and modelling to incorporate degradation rates (Carraro et al., 2020, Thomsen and Willerslev, 2015), this becomes a useful and valuable tool in understanding public health risk factors for users of the water environment.

However, this assessment is currently not possible in the majority of places, therefore indicating the levels of utilisation of waterbodies and reasons they are not used may build an understanding of where this data would have greatest impact, especially if concerns over pathogen levels are discouraging the community from using the water environment.

SOC3 – Human health An assessment of health outcomes using potential years life lost with additional assessment of current health data within overarching trends (Table 4-15).

Table 4-15: SOC3 – Human health. Details of proposed indicator

Metric	**Human health:** Assessment of population health outcomes based on human health index based on years of life lost (potential)		
Benchmark	Comparison against national statistics (quartile ranges)		
Benchmark visualisation	Target	Satisfactory	Inadequate
	Within lower quartile: less than 25% of areas have PYLL which is lower	Within interquartile range	Within upper quartile: more than 75% of areas have PYLL which is lower
'Healthcheck'	Cross-check with additional evidence sources (i.e. the overarching trend)		

Comparison of human health outcomes was considered an important element in assessments by the questionnaire respondents. Consideration of the potential years of life lost and comparison against national statistics allows identification of areas which are at the extremes of the national profile and enable action to increase equitability of health outcomes. Although these are not solely driven by the water environment it recognises the need to adopt a multi-faceted approach to assessments and future planning.

SOC4 – Proximity to green space An assessment using nationally available data on distances to public green space cross-checked against local knowledge (Table 4-16).

Table 4-16: SOC4 – Proximity to green space. Details of proposed indicator

Metric	**Green space:** Assessment based on average distance (m) between green infrastructure (not including domestic gardens) and residences		
Benchmark	Residences within 300m (5 minute walk) of public green space (Konijnendijk, 2023, Public Health England, 2020)		
Benchmark visualisation	Target	Satisfactory	Inadequate
	Area average less than 300m	Area average between 300m and 600m	Area average greater than 600m
'Healthcheck'	Cross-check with additional evidence sources to demonstrate utilisation by diverse local population		

In alignment with the Sustainable Development Goals (SDG); SDG11 (United Nations, 2015), this indicator recognises the importance of access to green space for societal well-being. It also reflects the link between water systems and green spaces (Zhao et al., 2020, Zheng et al., 2021). However, national measurements of proximity to green space have the potential to exclude green spaces that are not parks, public gardens or playing fields such as green corridors, and do not incorporate ownership that may impinge on public access, particularly in the case of playing fields. Further to this, proximity to green space may not be equivalent to accessibility or usage, as use of spaces, including urban spaces, is complex (Rogers and Hunt, 2019). Whilst the presence of green space will positively impact the urban heat island effect (Liu et al., 2021, Tiwari et al., 2021) and provide opportunities for greater levels of infiltration (Galli et al., 2021), the physical and mental health benefits to the community may be impacted by accessibility restrictions, either due to physical restrictions, safety concerns and time constraints or cultural value prioritisation. Therefore, a more nuanced assessment is required to understand whether impacts would be experienced across the community and the 'healthcheck' can start to decipher some of this complexity.

This highlights the connection between indicators, in this case SOC3 and SOC4, as within a complex system one attribute is likely to impact across many areas within the system. However, there are different combinations of factors that contribute to each indicator thereby making each a separate measure of a given outcome. Nevertheless, the potential for consequences, including unintended consequences, should be considered when assessing indicators and proposing subsequent interventions.

4.4.5.4 Economic indicators

The purpose of economic indicators is to evaluate whether the provision of water and wastewater services is supporting the ability of society and ecology to thrive. It is proposed that this assessment encompasses an assessment of the financial burden water and wastewater services place on localised communities, as well as how embedded the opportunities are to capture value from water and wastewater services.

ECO1 – Water service affordability An assessment of the financial burden of water and wastewater services within a community cross-checked against local knowledge and specific data sources (Table 4-17).

Table 4-17: ECO1 – Water service affordability. Details of proposed indicator

Metric	**Water service affordability:** Risk ranking based on household income		
Benchmark	Target for maximum spend to be less than 3% of household income (United Nations Childrens Fund (UNICEF) and the World Health Organisation, 2021) Using 2022 prices (Water UK, 2024a) the benchmark equates to a household income of £13,733/annum with some regional variation this is marginally above the average household income (after taxes and benefits applied) of the lowest decile within the UK (Office for National Statistics, 2023)		
Benchmark visualisation	Target	Satisfactory	Inadequate
	Less than 8% of LSOAs in lowest decile income bracket	8-15% of LSOAs in lowest decile income bracket	More than 15% of LSOAs in lowest decile income bracket
'Healthcheck'	Cross-check with additional evidence sources including local opinion and efficacy of payment protection schemes		

Assessment of the price of water compared to income level provides a high level indication, it would not incorporate the impact of metering on individual bills as it would be required to use average consumption rates due to the ethical implications of analysis at this level of granularity. The issue of providing payment protection and valuation of a public good remain and are substantial topics for consideration (Bowman et al., 2023, Dasgupta, 2021, Olmstead and Stavins, 2009, Reddy et al., 2015). Nevertheless affordability of water services is a growing concern for the water sector (Consumer Council for Water, 2021a) and was notable in English and Welsh water company PR24 business plans; for example Northumbrian Water (2023) and United Utilities (2023), which include extensive proposals for payment protection schemes. The presence and impact of payment protection schemes should be incorporated into this metric to provide a more thorough assessment. It should be noted that this indicator is by no means a perfect measure of affordability as it is subject to aligning multiple datasets and providing a relative comparison.

ECO2-ECO4 – Resource recovery The adoption of established and emerging recovery technologies within the water sector assessed across three categories (Table 4-18).

Table 4-18: ECO2-ECO4 –Details of proposed indicators relating to resource recovery

Metric	**ECO2 - Wastewater: basic recovery** Percentage of population equivalent with biosolids separated and treated with energy recovered and biosolids recycled to land		
Benchmark	Target for all wastewater treatment to adopt established recovery technologies		
Benchmark visualisation	Target	Satisfactory	Inadequate
	100% of wastewater population equivalent	More than 75% of wastewater population equivalent	Less than 75% of wastewater population equivalent
'Healthcheck'	Cross-check with additional evidence sources. Does recovery support a local circular economy		
Metric	**ECO3 - Wastewater: enhanced recovery** Percentage of population equivalent with recovery of nutrients and other emerging materials		
Benchmark	Target for all wastewater treatment to adopt enhanced recovery technologies		
Benchmark visualisation	Target	Satisfactory	Inadequate
	More than 80% of wastewater population equivalent	Between 30% and 80% of wastewater population equivalent	Less than 30% of wastewater population equivalent
'Healthcheck'	Cross-check with additional evidence sources. Does recovery support a local circular economy		
Metric	**ECO4 - Water: resource recovery** Percentage of population equivalent with recovery of water		
Benchmark	Target for water supply systems to integrate water recovery		
Benchmark visualisation	Target	Satisfactory	Inadequate
	More than 75% of supply connections utilise water recovery	Between 25% and 75% of supply connections utilise water recovery	Less than 25% of supply connections utilise water recovery
'Healthcheck'	Cross-check with additional evidence sources. Does recovery support a local circular economy		

In the UK the treatment of wastewater biosolids to generate energy and nutrient rich fertiliser is well established. The resource recovery potential of this is expanding as enhanced digestion (Water UK, 2020) is adopted across the industry to both increase the potential for the treatment site to be energy neutral and to increase the land bank available within which to utilise treated biosolids.

The second category of resource recovery assessment relates to the adoption of emerging areas of resource recovery to support a regenerative and circular economy in alignment with net zero ambitions (Water UK, 2020). This is an aspirational indicator that reflects a movement towards circularity and recognition of the potential value held within a substance that is typically referred to as a waste. Additionally, the recovery of products that have a value increases the financial viability of the water sector since this represents an income stream that can offset the cost of treatment and supply of water and wastewater services.

The final category of resource recovery assessment (ECO4) relates to the adoption of water reuse, which would increase the sustainability of the water sector in the face of forthcoming climate change related challenges (Ofwat, 2019). Although extremely limited in the UK currently, there are growing pressures on water resources and therefore a requirement to consider water reuse and overcome the reluctance of the population to adopt these measures when scarcity is not commonly considered an issue (Duckett et al., 2024). There are, however, developments in this area with indirect water recycling as part of the Regulators' Alliance for Progressing Infrastructure Development (RAPID) and water resource solutions (Ofwat, 2023a).

4.4.6 Application at operational catchment and waterbody scale

Indicators (Table 4-19) provide an overall assessment for a defined area, and become particularly effective when they can be visualised in a concise form and used for comparisons between areas (Figures 4-32 and 4-33).

Table 4-19: Summary of proposed indicators

Abbreviation	Descriptive title
ENV1	Ecological status
ENV2	Chemical status
ENV3	Wider environmental impact
ENV4	Physical modification
SOC1	Potable water of sufficient quality
SOC2	Environmental pathogen levels
SOC3	Human health
SOC4	Proximity to green space
ECO1	Water service affordability
ECO2	Wastewater: basic recovery
ECO3	Wastewater: enhanced recovery
ECO4	Water: resource recovery

The relative differences in ecological status, level of physical modification and income level between the Leven and Upper Mersey (Bollin Dean) operational catchments are evident across the indicators (Figure 4-32). However, it should be noted that this assessment does not allow for the demonstration of nuance between actual values within the bandings defined for each indicator. For example SOC4 (Access to blue-green infrastructure) is 'satisfactory' for both operational catchments, however the actual average values are 305m within the Upper Mersey (Bollin Dean) and 567m within the Leven, demonstrating that whilst the former is very close to achieving the target value of less than 300m, the latter is much closer to a value of

600m considered the upper bound of acceptable for achieving good access (Konijnendijk, 2023). This demonstrates a potential flaw with the use of indicators as they can mask the details behind the assessment, therefore they should be regarded as an overview summary which may guide and advise further assessment.

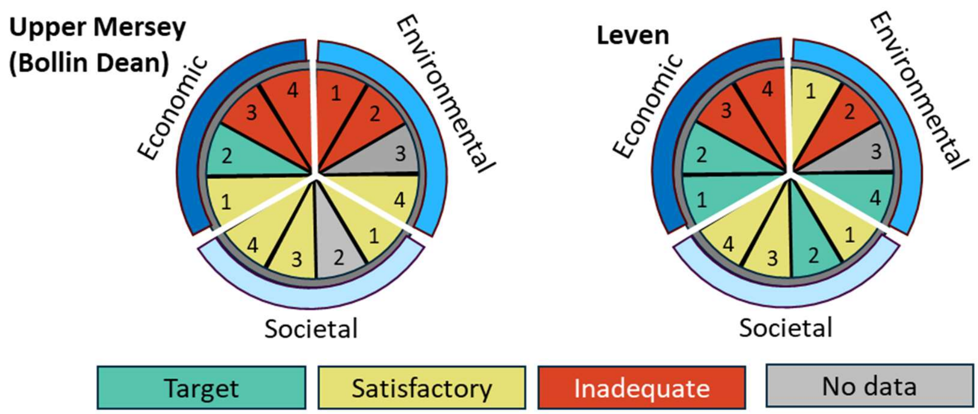


Figure 4-32: Visual representation of indicators for the operational catchments of the Upper Mersey (Bollin Dean) and Leven. Numbers within each spoke relate to the indicator e.g. under the environmental header ENV-1, ENV2 etc.

Notably no data was available for ENV3 (Wider environmental impact) as this is not publicly reported data. The water company is however required to record this information, therefore as part of a collaborative process it is feasible that this would be available. Additionally, there is geographical variability in data availability for some indicators, notably SOC2 (Environmental pathogen levels) which is not available within the Upper Mersey (Bollin Dean) operational catchment, yet it was available for the Leven operational catchment due to Windermere within the Leven being one of the limited number of inland waters designated as bathing waters.

The waterbody Mersey upstream of MSC within the operational catchment Upper Mersey (Bollin Dean) provides an example of the visual representation of indicators within a single waterbody, albeit a large and complex waterbody covering several residential areas and 35km in length (Figure 4-33). Whilst the graphics displayed in Table 4-7 required the comparison of multiple datasets within separate graphics, here they have been condensed into a single visualisation using bandings of indicators to summarise the information contained within the assessment. Areas A-2, D, F and G are noticeable as having fewer indicators assessed as ‘target’. The comparison of environmental indicators against social and economic indicators is

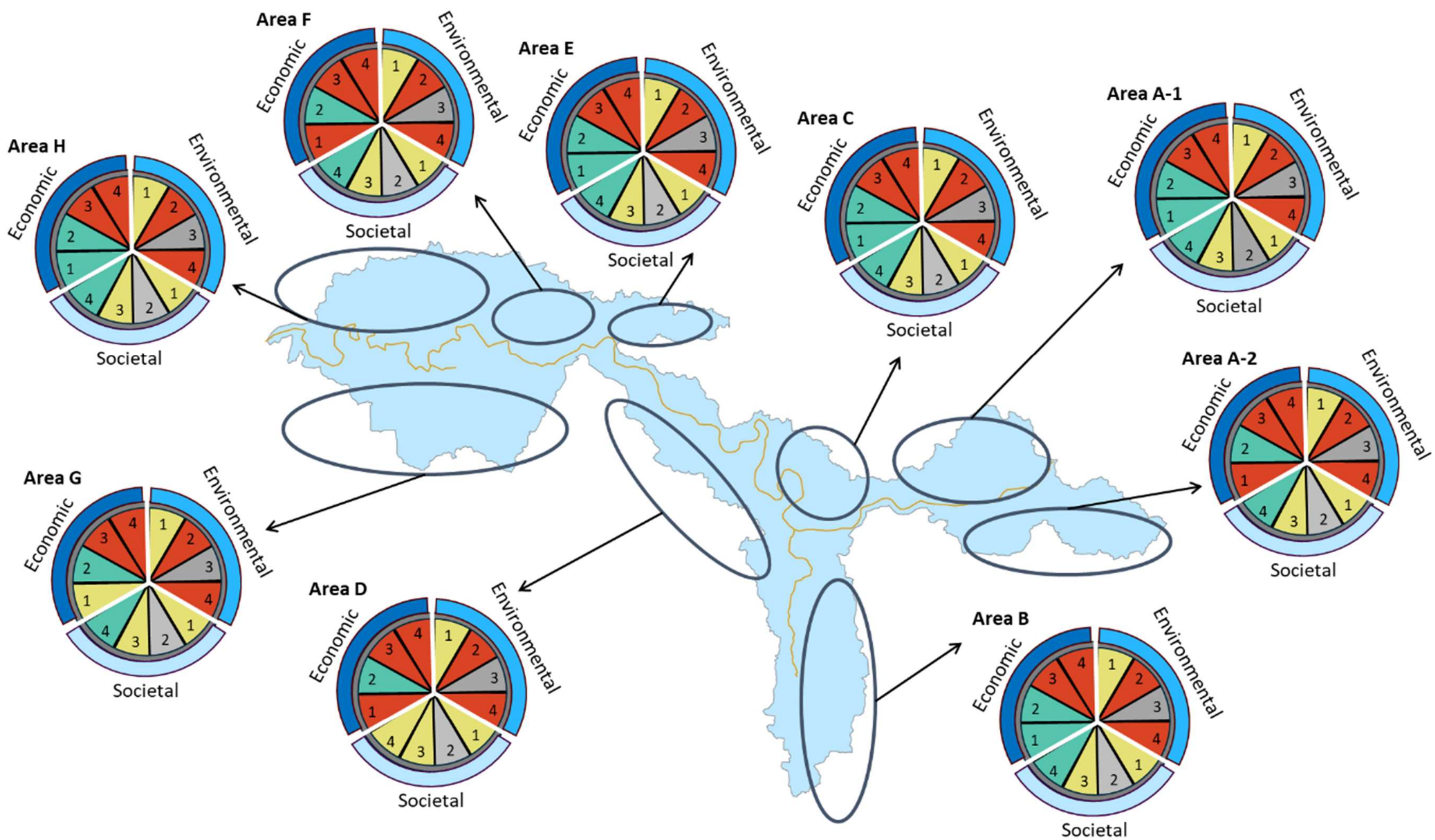


Figure 4-33: Visual representation of indicators within the Mersey (upstream of MSC) waterbody

prevented as this is a single waterbody; moreover, this assessment has not been completed using collaborative methods and local knowledge. For a complete assessment this stage of data 'healthcheck' is vitally important to identify variations in the system that do not become apparent from data aggregated at the waterbody scale, particularly where the waterbodies are extensive. Additionally, the analysis alongside map-based data sources which could be overlaid such as land use and flood risk will provide an additional depth of understanding.

Considering the quantity of available water to all potential users leads to assessment of the amount of renewable water within a catchment. In the UK water resources are managed on a regional, rather than catchment basis due to the small nature of UK catchments and high levels of population density, which mean that water has been transported across regions for over a century in order to maintain urban and industrial centres (Greenwood, 2018). Indeed, water transfers are due to increase in response to population growth and climate change impacts (Ofwat, 2023b, Ofwat, 2023c). Land use also impacts the water system and assessment of land use can provide indications of small scale, un-licenced (Department for Environment Food & Rural Affairs, 2021b) abstractors as well as indicating the potential for sources of diffuse pollution and opportunities for landscape-scale initiatives.

5 DISCUSSION

The following chapter presents a discussion of the application and impacts of the tools which have been developed. Section 5.1 discusses the role of systems maps and causal loop diagrams in analysing the drivers of policy, attitudes and behaviours using evidence-based mapping and future scenarios. The role of future scenarios is further explored in the consideration of indicators (Section 5.2), including how these interact and are supported or pressured as alternative futures unfold. The next two sections of this chapter include the outputs from Objective 6 (Application at different tiers of practice) to explore the impacts of the tools which have been developed across the realms of value, social norms and technology. Section 5.3 provides a discussion of research outputs in the consideration of the value of water within society and the impact of price mechanisms. Finally, Section 5.4 considers the role of the tools developed herein to the development and implementation of new innovations, in this case Pipebots.

5.1 Applying visualisations

5.1.1 System maps to enable appraisal of surface water systems

The application of system mapping, be it evidence-based or through participatory methods, must recognise that the resultant 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 4-2 to 4-4). 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 (Figures 4-8, 4-12, 4-16 and 4-20). 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).

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 behaviours (Figure 4-21). The impacts are ultimately governed by both hard and soft governance, the latter including the incumbent attitudes and behaviours of society which are a product of cultural evolution (Farley et al., 2020). This can be summarised 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, behaviours 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 USA: water use reduction was successfully achieved in response to the Millenium Drought in Australia; however the inelasticity of water consumption behaviour has led to a gradual return in consumption levels as the risk 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."*

These examples demonstrate the recalcitrance of behaviours 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., 2019b), although decreases have also been observed (James et al., 2023, Radcliffe and Page, 2020). An interplay can be said to develop between policy and behaviour due to the nature of societal behaviour as a product of the prevailing culture, policy and norms. This is pertinent when interventions seek to embed new policy or behaviour. This concept is explored further in Section 5.3.

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 behaviours (Farley et al., 2020). Although multiple views and theories can exist concurrently, one will dominate policy development and subsequent behaviours of the time. Evidence of exposure to market-driven economic theory and reduction in egalitarian behaviour (Farley et al., 2020) demonstrates how closely linked policy and collective behavioural traits are.

Analysing the four key determining factors through the development of a conceptual model has focused on three central, interconnected loops, which are discussed in turn below. Attitudes and behaviours , i.e. social norms and value systems, form a pivotal role in driving and perpetuating these behaviours; this is unsurprising given the influence of human activity on the natural water cycle (Figure 4-1 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).

5.1.2 Product generation loop

A reinforcing, virtuous loop (Figure 5-1) forms between circular production, ecosystem resilience and biodiversity, public health, satisfaction and social cooperation. Increasing social cooperation leads to greater levels of egalitarian behaviour and an increasing tendency to adopt behaviours 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 behaviour 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 favouring circular processes over linear processes. Therefore, the consumption rate exacerbates the reinforcing feedback loop.

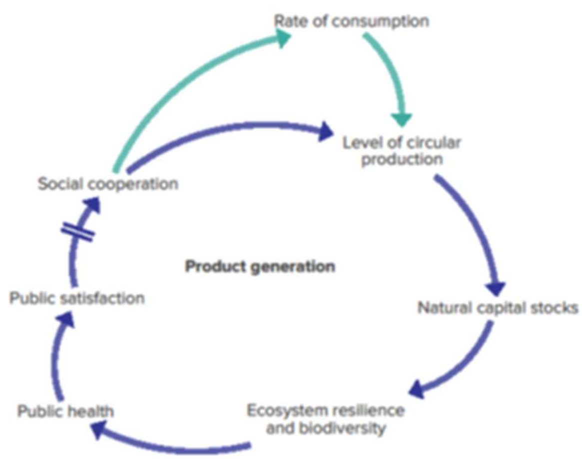


Figure 5-1: Conceptual model (Section 4.3) showing isolated Product generation loop

5.1.3 Urban development loop

Considering the impacts of urban development that encompass water resources, stormwater management, treatment capacity and treatment capability, a reinforcing virtuous loop (Figure 5-2) 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 realisation of impacts.

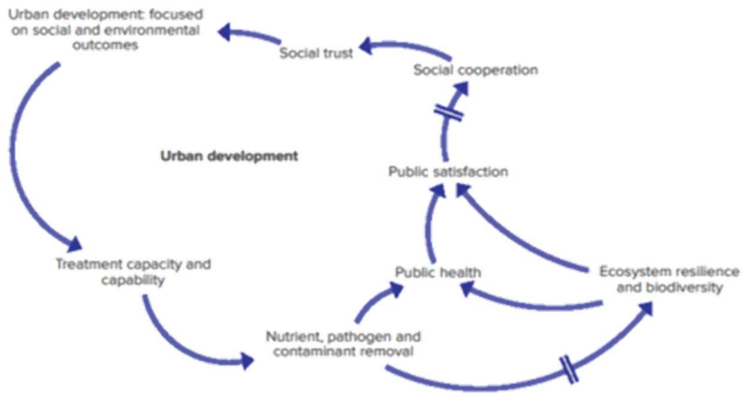


Figure 5-2: Conceptual model (Section 4.3) showing isolated Urban development loop

5.1.4 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 5-3). 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 towards less egalitarian attitudes and behaviours (Ramalingam and Stoddard, 2024). How this balance of values manifests through organisational 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.

Figure 5-3: Conceptual model (Section 4.3) showing isolated Value and cost recovery loop

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.

5.1.5 Impact of innovation within the conceptual model

The conceptual model (Figure 5-4) includes three reinforcing loops which each include innovation as a common means to create either incremental or transformational shifts. Within these loops there are a number of potential opportunities for innovation to impact the rate of consumption which have been highlighted in Figure 5-1. Influences within these nodes have impacts across the system; this will be assessed for two potential innovations in the form of governance systems for water pricing (Section 5.3), and a specific technology under development (Section 5.4).

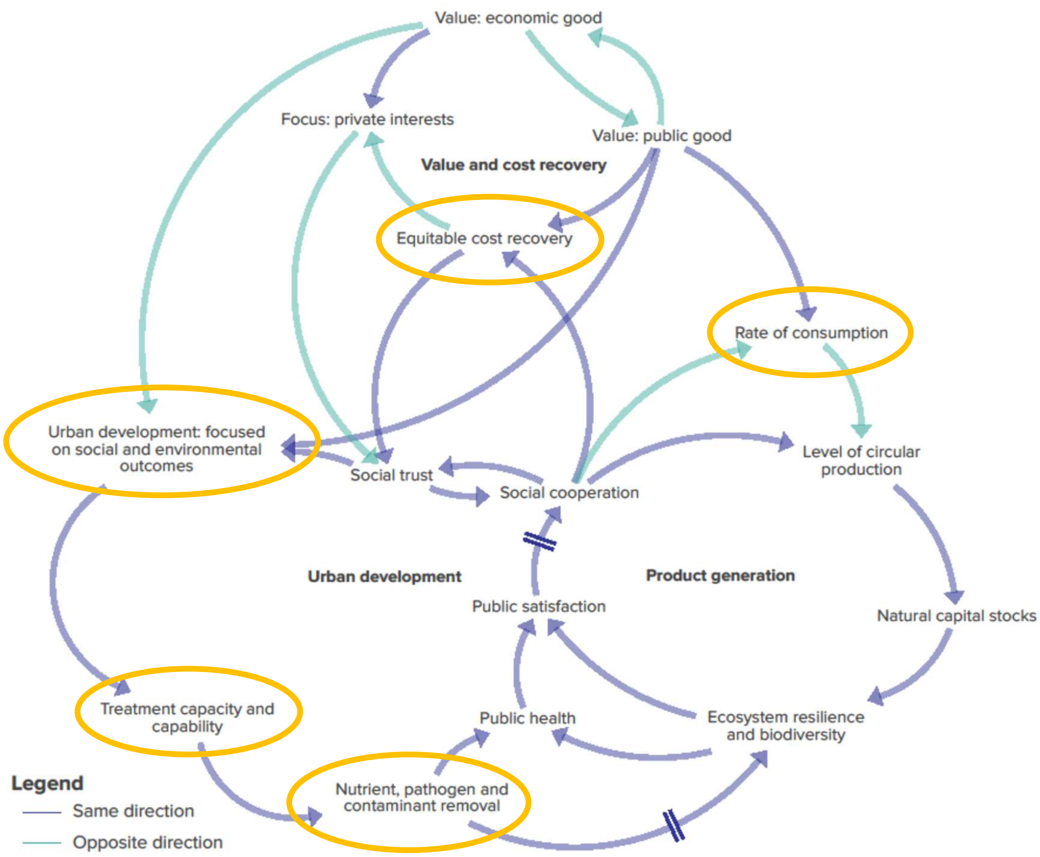


Figure 5-4: Conceptual model with nodes highlighted (yellow circles) which the implementation of innovation could influence

5.2 Indicators and future scenarios: interaction and relevance

Indicators (Table 5-1) provide a comparable means to complete assessments; when applied across geographical areas they provide insights into priorities for interventions. However, these interventions will operate under variable conditions, therefore consideration of how the outcome of interventions, as measured using indicators, will be impacted by future scenarios becomes highly relevant.

Table 5-1: Summary of indicators proposed in Section 4.4.5

Abbreviation	Descriptive title
ENV1	Ecological status
ENV2	Chemical status
ENV3	Wider environmental impact
ENV4	Physical modification
SOC1	Potable water of sufficient quality
SOC2	Environmental pathogen levels
SOC3	Human health
SOC4	Proximity to green space
ECO1	Water service affordability
ECO2	Wastewater: basic recovery
ECO3	Wastewater: enhanced recovery
ECO4	Water: resource recovery

5.2.1 Variable influences on indicators

Environmental indicators (Table 5-2) encompassing ecological status (ENV1), chemical status (ENV2) and physical modifications (ENV4) are put under increasing pressure in a **market forces** scenario. An emphasis on market process and the protection of individual interests reduces environmental protection (Figure 5-4) leaving this open to degradation. Existing global agreements and pressures continue to exert pressure on adherence to greenhouse gas emission targets and the wider impacts of water service provision (ENV3). This external pressure also remains present in a **policy reform** scenario meaning that influences on this indicator remain stable. Conversely within a policy reform future scenario there is increasing policy-based protection in place supporting both ecological and chemical status (ENV1 and

ENV2) whilst physical modification (ENV4) is actively reduced to minimise fragmentation of the water system. However, this effect is moderated by a behavioural shift and public opposition to top-down policies. A **fortress world** scenario is one in which environmental protections (ENV1-4) are de-prioritised as social structures polarise generating elite enclaves within which individual interests are protected at the expense of the wider environment. Those outside the fortresses are disenfranchised and unable to influence this outcome. The diametrically opposed future summarised within the **new sustainability paradigm** scenario emphasises the impact that combined behavioural and societal priority shifts can have on environmental impacts (ENV1-4); these are supported by policy structures and a population willing to support their implementation.

Table 5-2: Influences on environmental indicators across future scenarios.

Indicator	Market Forces	Policy Reform	Fortress World	New Sustainability Paradigm
ENV1	↷	⇗	⤵	⬈
ENV2	↷	⇗	⤵	⬈
ENV3	→	→	⤵	⬈
ENV4	↷	⇗	⤵	⬈

Key: ↷ - Indicator under pressure, ⤵ Indicator under high pressure. ⇗ Indicator is supported, ⬈ Indicator is highly supported. → Indicator is stable.

Considering societal indicators (Table 5-3) similarly demonstrates the impact of policy and behavioural attitudes as influences on indicators.

Table 5-3: Influences on societal indicators across future scenarios.

Indicator	Market Forces	Policy Reform	Fortress World	New Sustainability Paradigm
SOC1	⟶	➪	🔀	➦
SOC2	↷	➪	⤵	➦
SOC3	↷	➪	🔀	➦
SOC4	↷	➪	🔀	➦

Key: ↷ - Indicator under pressure, ⤵ Indicator under high pressure. ➪ Indicator is supported, ➦ Indicator is highly supported. ⟶ Indicator is stable. 🔀 Impact is highly variable.

A **market forces** future in which individualistic and libertarian attitudes predominate exerts increasing levels of pressure on environmental pathogen levels (SOC2), human health index (SOC3) and proximity to green spaces (SOC4) as these are associated with actions that support collective benefits regardless of individual gain. The pressures on potable water quality (SOC1) remain constant as there is no increasing level of scrutiny but also this is not diminished by competing priorities, i.e. there is no compelling reason to lower standards or to reduce the ability with which these are met. A **policy reform** future leads to structures that widely support societal indicators (SOC1-4) due to the high importance granted to social justice within policy development. There is some public criticism to top-down policy implementation, particularly where this may result in changing behaviours, which results in variability in the success of policies and therefore the ability to reach target benchmarks across a number of societal indicators. Therefore, although these indicators are supported, they may not be universally adopted; indeed geographical variation is likely to occur associated with localised prioritisation.

A **fortress world** scenario is characterised by societal breakdown leading to diverging outcomes between elites in enclaves and the rest of the population. The assessment of indicators within this scenario would be highly geographically and demographically variable with strong negative influences outside of the enclaves and protection measures in place within enclaves to ensure that elite communities are not negatively impacted. This is particularly true for SOC1, SOC3 and SOC4, whereas SOC2 (environmental pathogen levels) is put under increasing pressure due to infrastructure collapse and the disintegration of protection of the environment. **New sustainability paradigm** is a scenario in which behavioural changes and policy combine to provide substantial support across all societal indicators (SOC1-4).

Economic indicators (Table 5-4) demonstrate the impact of variation in prioritisation and consideration of value.

Table 5-4: Influences on economic indicators across future scenarios.

Indicator	Market Forces	Policy Reform	Fortress World	New Sustainability Paradigm
ECO1	⤵	⇗	⇗ *	⬈
ECO2	⇗	⇗	→ *	⇗
ECO3	→	→	⤵ *	⇗
ECO4	⤵	→ *	⤵	⇗

Key: ⤵ - Indicator under pressure. ⇗ Indicator is supported, ⬈ Indicator is highly supported. → Indicator is stable.
** Some degree of nuance or uncertainty highlighted within the accompanying text.*

A **market forces** future scenario has variable impacts across economic indicators. A market-driven approach to provision of water services exerts additional pressures on affordability (ECO1). There is an emphasis on profit generation within service providers with limited protections in place to ensure affordability across the whole of society. Resource recovery, or product generation, is supported across existing areas of biosolids and biogas generation

(ECO2). Limited innovation and reluctance to generate novel markets results in the recovery of nutrients continuing at the current rate (ECO3), and developments into water reuse stagnating (ECO4). A similar outcome regarding recovery of resources (ECO2-3) is apparent in a **policy reform** future scenario although in this instance some indirect water reuse may be encouraged to mitigate environmental pressures (ECO4), however the strong emphasis on social outcomes means that affordability is supported by social policy (ECO1).

Within a **fortress world** scenario the cost of water services could be seen to diminish (ECO1), however this is accompanied by a restriction in service provision and the possibility of private water vendors being used which typically supply water at a premium (Ahmad, 2017, Opryszko et al., 2009, Plappally and Lienhard, 2012). The ability to produce biogas is continued where possible, although as time progresses this becomes increasing difficult to maintain (ECO2). The lack of emphasis on innovation reduces interest in the recovery of nutrients (ECO3) or water (ECO4) and therefore these areas reduce in importance although there is potential for opportunistic recovery to arise. Contrastingly, a **new sustainability paradigm** future supports all indicators (ECO1-4) including the recovery of resources. The predominance of material sufficiency attitudes increases public acceptance of recovered resources and thereby creates markets to support product generation.

Unsurprisingly, given the NSP scenario alignment with environmental justice objectives, this future scenario encompasses the policy, behaviour and value attitudes to align with the proposed indicators. Across all scenarios the balance between these attitudes is integral to the shift in outcomes that can be expected.

5.2.2 Considering the impacts within a specific locality

The impacts of shifting influences on indicators across alternative futures can be explored specifically for a given locality; this analysis revisits the waterbody explored in Section 4.4; Upper Mersey (upstream of the MSC) (Table 4-7).

Market Forces

Indicators relating to water quality (ENV1 and ENV2) are under pressure due to a focus on markets and financial viability limiting appetite to take substantive action to reduce contamination and embedding societal behaviours which support individualistic actions. These attitudes also restrict further reductions to the wider environmental impact of the water system within this locality (ENV3). The waterbody is currently categorised as ‘satisfactory’, and this could deteriorate to ‘inadequate’ based on the indicator benchmarks. Limited action is undertaken to remove modifications of the waterbody, although further modifications are restricted (ENV-4). Nevertheless, habitats are likely to remain fragmented and under stress.

Societal indicators are under pressure; this is especially pertinent for Area D which currently has a lower ranking for SOC4 (Proximity to green space), compared with other areas within this waterbody. Limited changes are anticipated for SOC1 (Potable water quality) as the existing service standards remain consistent, similarly the lack of environmental pathogen level monitoring currently in this locality continues meaning that no data is available for SOC2. Increasing urbanisation, in an already urban area, and a tendency to use grey infrastructure for urban development increases pressure on mental and physical well-being (Figure 4-8) which manifests as increasing pressure on SOC3 (Human health).

Affordability of water services (ECO1) currently shows wide variability across the areas within this waterbody, this is likely to widen under a MF future scenario leading to increasing levels of public distrust and disillusionment particularly where these areas are in proximity to each other i.e. Areas A1 and A-2 as well as Areas E, F and H. Market opportunities for biogas and biosolids recovery (ECO2) are already well established within this locality. Although this will not decrease, there is limited scope for consideration of alternative recovery options (ECO3 and 4) due to a recalcitrance to consider novel products, predominance of the linear economy and widespread public distrust.

Policy Reform

The natural environment is likely to show some improvements in quality (ENV1,2 and 4) as there is increasing focus on the use of policy and environmental regulations. Prioritisation of natural capital in investment decision-making provides a platform to support improvements and some remediation of modifications to waterbodies. Whilst there is a policy focus on reducing wider environmental impacts (ENV3) this is countered by indirect emissions and does not constitute a substantial change from the current situation.

Societal outcomes are supported in a PR scenario due to the strong social policies characteristic of this scenario. This is especially beneficial for proximity to green space (SOC4) within Area D and for health outcomes (SOC3) across all areas, although improvements are limited by the complexity of factors that contribute to these indicators.

A policy focus promoting equitable distribution of costs for water services results in affordability being a primary concern. The development and effective implementation of affordability measures eases the financial burden of water services (ECO1) in areas where this is a substantial concern, notably Areas A-2, D, F and, to a lesser extent, Area G. The recovery of biogas and biosolids (ECO2) is already established, there is limited incentive to consider other forms of recovery (ECO3), including water recycling (ECO4), due to the prevailing public opinion of water abundance and reluctance to accept top-down policy.

Fortress World

Increasing levels of polarisation and breakdown of collective action and protection leads to a deteriorating water environment (ENV1-4) and greater inequity between social outcomes (SOC1-4). The variability in outcomes between areas is likely to increase with growing differences between areas A-1 and A-2, as well as between Areas E, F and H. Physical barriers between some of these areas such as the River Mersey itself or major road infrastructure such as the motorway, will increase physical separation between communities. ENV1 and SOC2 are expected to show the greatest deterioration compared to the current situation. Resource recovery may be opportunistic and increase risks to those individuals that engage with recovery activities directly due to a lack of regulation and controls (ECO2-4). The provision of centralised water services deteriorates leading to a range of costs associated with water (ECO1); private water vendors provide water at a premium, whilst others may use unregulated sources out of necessity. Alternatively, centralised services may be available within elite enclaves, however the service offered will be considerably restricted in remit.

New Sustainability Paradigm

Changes to social attitudes and behaviours along with shifts in policy lead to improvements across all indicators compared to target benchmarks. Decentralised approaches lead to, and form from, greater public awareness and engagement with the water system. This positively reinforcing relationship is compounded by material sustainability decreasing consumption and increasing the utilisation of recovered resources.

Urban redevelopment is widespread, increasing resilience to climate change and external threats through repurposing and modifying existing structures and infrastructure. The resultant change to urban structure increases the delineation between rural and urban areas, including the repurposing of areas, especially Areas B, D, G and H.

5.2.3 Implications for decision making

The ability to enhance assessments of current performance against environmental justice-led benchmarks, with consideration of future socio-economic contexts, provides valuable insights into the system and priorities within this system. This has the potential to enable areas of particular risk to be identified, including geographical variation within risk susceptibility. This contributes to a collaborative and transparent development of needs incorporating long-term risks associated with attitudes, behaviours and policy.

5.3 The value of water – application of visualisations and indicators to incorporate environmental justice goals into assessing water pricing measures

There is a tendency to move towards a view that if a NSP scenario enables environmental justice-led outcomes then this is the epitome of governance structure that should be developed. However, the NSP scenario only achieves these outcomes due to behavioural and attitude shifts and, as with all socio-economic systems is subject to externalities. Indeed, this is the very objective of using future scenarios, to test governance measures, urban development and interventions, against external pressures. The next section considers the impact of water pricing structures as mechanisms to increase societal value of water and support movement towards targets across multiple indicators with a particular focus on affordability, i.e. how might environmental justice-led water pricing measures that have been developed react across alternate futures. This uses the outputs of research undertaken by the author and others which has been published as '*The water pivot: transforming unsustainable consumption to valuing water as a resource for life'* presented in Appendix G).

5.3.1 Proposed mechanisms to transform the value of water within society

The provision of water services involves the consumption of energy and chemicals, supports employment across a range of skill sets, and requires frequent capital projects to provide environmental improvements. These may be considered the direct costs associated with the provision of water services, however there are further costs associated with the opportunity cost and both environmental and economic externalities (Barraqué, 2020). To truly encompass these costs and increase transparency of delivering water and sanitation services, they should be incorporated into the price paid. This has inherent complexity due to the heterogeneity of water (as discussed in Section 2.3) in multiple aspects of its human and non-human functionality leading to an almost infinite number of prices. Consequently, the construction of a market-driven approach to water pricing is rife with opportunities for injustice to manifest.

A combination of place-based, market-driven and policy approaches to the provision of water services may support more equitable structures. A place-based approach enables local context to be embedded; the transparency of this is paramount. As has been observed from the impact of the Sewage Map (The Rivers Trust, 2024b) in raising awareness and gathering momentum for action there is greater ability to collaborate and amplify community voices and concerns through use of an accessible tool. In the case of the Sewage Map this is constrained to a single issue and does not reflect the scale of complexity of the water system. The use of multiple perspective system maps and visualisations of key indicators through open platforms would enable cooperation on more complex issues, enabling collaboration and societal agency over the actions undertaken to provide ongoing water services. Further to this the ability to visualise and increase the accessibility of information regarding surface water systems using a place-based approach, by increasing societal involvement, increases the value ascribed to surface water systems.

The impact of consumption on the surface water system is two-fold; the amount of water consumed, and the negative impact of the wastewater subsequently returned to the surface water system. Frequently, water resources management research focuses on the first of these without thorough consideration of the latter (Ahmadi et al., 2020, Gurluk and Ward, 2009, Kumar et al., 2016, Piniewski et al., 2014, Tomlinson et al., 2020, Wada et al., 2017). Much research has been undertaken into the minimum level of domestic water consumption that should be achievable (Hunt and Rogers, 2014); this can be used as the basis for an 'essential' water allocation above which additional consumption would result in an increased unit cost using rising block tariffs. This type of mechanism is in use globally and there are opportunities for this to lead to unjust consequences as in the cases of Pheonix (see discussion in 2.3.2.3) (Zhu et al., 2023) and Sacramento (Simpson et al., 2023), USA. There are also opportunities for the rising cost to have little or no effect on consumption as domestic consumption is typically inelastic to price (Luby et al., 2018, Olmstead et al., 2003) and heavy users do not identify as such (El-Khattabi et al., 2021). Therefore, to enable pricing mechanisms to support environmentally just outcomes the interaction of policy approaches and how these may, or may not, support pricing mechanisms becomes critical. Policy measures to ensure affordability of ‘essential’ water provides protection of the human right aspect of water provision. Additionally, this enables the rising block prices to be set high enough to elicit a consumer response and be in line with ecological requirements, including seasonal variations, incorporate the impact of impairment on water systems and contributions to greenhouse gas emissions. The combination of policy measures and open communication of concerns has the objective of enabling the use of market mechanisms without fully commodifying the provision of water services. If successful, this would encourage the consideration of water as predominantly a public good whilst inhibiting the tendency for this to result in increasing consumption rates (Figure 5-5).

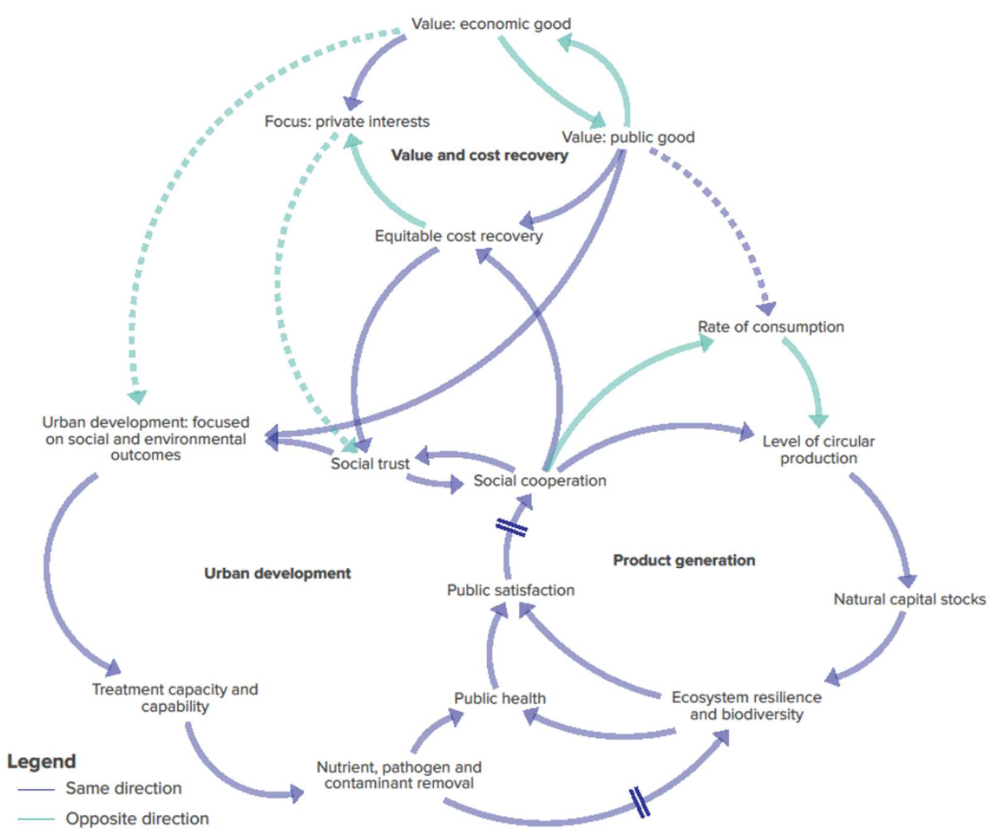


Figure 5-5: Conceptual model modified to show the impact of justice-led policy supported water pricing mechanism. Dashed lines indicate the reduction of influence across critical pathways

Creating a focus on equitable cost recovery is supportive of the view that water is a public good. To achieve this, it would need to be equitable in terms of environmental impacts, i.e. ecological externalities are embedded within the cost, as well as societal impacts. Coupling this with policy and pricing instruments that make evident the impacts of overconsumption and impairment whilst also increasing societal ownership of the water system (Figure 5-6) counter the tendency for public goods to be exploited. Equally the tendency for water to be commodified is limited and policy structures are in place to ensure that private interests are not pursued in detriment to social and environmental outcomes. To be effective governance bodies (water guardian and legal agent) are required to perform specific functions whilst providing independency and representation.

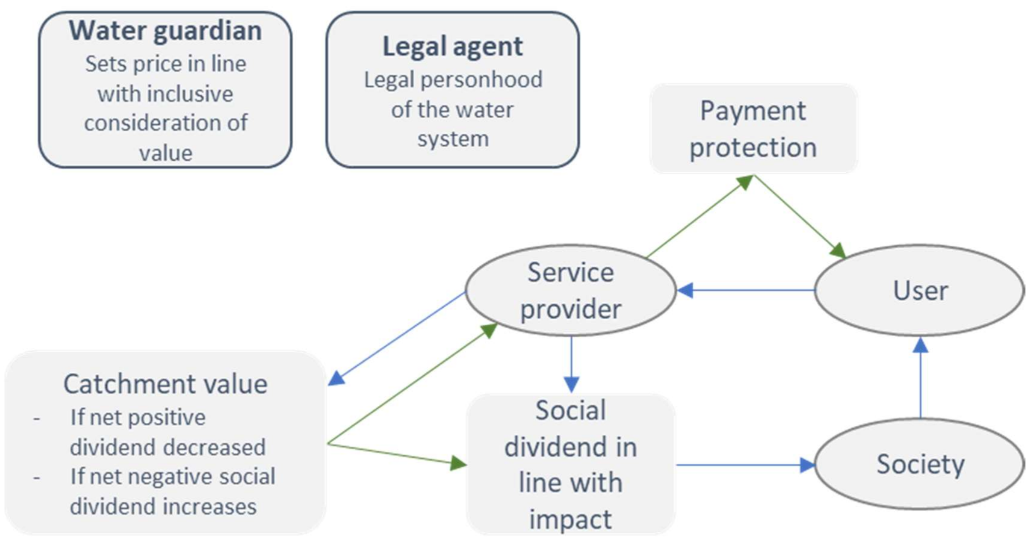


Figure 5-6: Key interactions within water pricing mechanism set out in Bowman et al. (2023) . Green arrows represent influencing mechanisms, blue arrows represent transfer of money. The water guardian and legal agent are proposed governance bodies to provide inclusive representation and independency.

An assessment of the potential impacts that water pricing mechanisms supported by environmental justice-led policy instruments could have on indicators (Table 5-5) demonstrates that there is potential for mechanisms such as these to lead to positive impacts across environmental, societal and economic spheres.

Table 5-5: Impact of water pricing mechanisms on indicators

Indicator	Impact	Interaction
ENV1	➦	Incorporation of environmental impacts within the pricing mechanism at the service provider level enables the impact caused on the water environment to be incorporated to incentivise proactive action to reduce this impact.
ENV2	➦	
ENV3	➦	
ENV4	➩	Opportunity for the service provider to invest in improvements to catchment value to offset the requirement to provide a social dividend.
SOC1	⟶	Marginal impact
SOC2	➩	Opportunity to incorporate social value of low environmental pathogen levels into catchment value assessment by the Water Guardian
SOC3	➩	Opportunity for an improved environment to result in mental and physical health benefits.
SOC4	➩	Opportunity for the service provide to invest in provision of green space to support improvements to catchment value. Alternatively, opportunities for community-led action funded through the social dividend
ECO1	➦	Provision of payment protection directly supports the affordability of water services. Social dividend serves to provide wealth redistribution
ECO2	➩	Through supporting inclusive consideration of the value of water and improving the transparency of this supports movement towards a circular economy and therefore increased opportunities for resource recovery
ECO3	➩	
ECO4	➩	

Key: ➩ – Indicator is supported, ➦ highly supported. ⟶ – Indicator is stable.

A water pricing mechanism of this sort enables the dichotomy of water as both a public and an economic good to be incorporated into a pricing mechanism that is driven by an environmental justice approach. At the organisational level water price instruments are employed to embed ecological impacts within the pricing mechanism, this is positioned as far up the value chain as possible in order to influence actions systemically. At the individual level price protection measures ensure the provision of water services as a human right and influence behaviours to reduce consumption in line with both the value of the activity and the availability of water.

5.3.2 Testing pricing measures against alternative future scenarios

Considering alternative future scenarios demonstrates how the development of governance approaches, such as pricing mechanisms, can be developed to enable adaptation to future requirements. The overall impacts are considered at the organisational level and from the perspective of individual users within society, including a discussion of the relative value ascribed to water within each future scenario.

Market forces

At an organisational level, governance structures are focused on market opportunities leading to increased interest in the role of trading opportunities to address environmental impacts and offset ecological opportunity costs. However, this also has the potential to result in geographical variation in water system impacts depending on the ability for the user to pay to off-set impacts, or historic localisation of infrastructure leading to compounding impacts for some communities.

A short-term focus which prioritises the interests of private finance exerts pressure onto the level of influence that both the legal agent and water guardian are able to enact. Ultimately this leads to compromises to environmental and social outcomes to protect commercial interests.

At the individual scale, diminishing social policies lead to payment protection mechanisms coming under threat, increasing opportunities for inequity and unjust outcomes. There is an individualistic response to water use and a commodification of water both in terms of consumption and the water environment which run counter to protection measures exerting pressure on their acceptance and effectiveness.

Policy Reform

The top-down policy approach characteristic of this scenario embeds responsibility of the legal agent and water guardian as integral parts of the governance structure ensuring that ecological costs associated with water services are embedded within cost recovery mechanisms. This is coupled with market-based mechanisms to drive the use of private finance for innovation whilst core water sector services are delivered through social enterprise to address social equity. This separation of responsibilities helps to ease tension between policy- and market-based mechanisms. Nevertheless, a tension does arise regarding tradeable rights and setting the shadow price of water, this impacts the marginal value and thereby (in)elasticity to price with the potential to result in unjust impacts across communities (as discussed in Section 2.2 and 2.3).

The strong emphasis on social equity leads to effective payment protection mechanisms which increase the equitability of affordability at the individual scale. However, there is also a public backlash against top-down policy especially where this is implemented in spite of the local context and where indirect unjust consequences become apparent. This is tempered by increased societal recognition of concerns although there are limited mechanisms to translate this into centralised action, and criticism of rising block pricing remains. The combination of policy and market mechanisms reflects the dualistic nature of water, and this is reflected in public perception of water as both a commodifiable asset and protected as a public good. This creates some conflict as these views are expressed to varying degrees.

Fortress World

A breakdown of governance structure and mechanisms lead to a legal agent and water guardian that have either no, or a substantially limited, water service provider over which they are able to exert influence. Therefore, the power of these entities disintegrates along with the ability to incorporate the ecological costs of water use into the value chain. Furthermore, there is a growth in private water vendors reducing the ability for centralised control over the quality and cost of water services.

At the individual level, a breakdown of governance systems increases public health risks that communities, especially those outside enclaves, are exposed to. There is substantial disparity in the experiences of individuals depending on their affluence, increasing opportunities for injustice. In all cases there is commodification of water and disregard to the environmental impacts due to disassociation with the natural world on the part of elite communities and prioritisation of needs following Maslow's hierarchy within the remainder of the population.

New Sustainability Paradigm

Within this scenario governance structures prioritise opportunities for circular processes and re-use leading to a shift in the consideration of water use from a linear process to one which is cyclical. This shift is led by society through changing attitudes and behaviours, ultimately leading to a reduction in consumption in line with social values. This impacts not only direct domestic consumption but also the use of water in the production of goods and services. The governance systems in place to minimise consumption have the potential to become superfluous to driving an understanding of value, leading to complacency over the embedment of such mechanisms over time.

The prevalence of material sufficiency as the preferred lifestyle of the population leads to collective and individual agreement that water is valued even when abundant. Community engagement and effective payment protection mechanisms lead to equitable pricing and wealth redistribution increasing the provision of justice-led outcomes.

5.3.3 Developing water pricing mechanisms

The complexity of interactions and impacts across these four alternative future scenarios demonstrates why mechanisms that rely on price alone, as well as having substantial potential to lead to inequitable outcomes, are unlikely to remain effective across different contexts.

The risk of market-based mechanisms dominating processes leading to increasing pressure to make compromises on environmental and social outputs is a significant concern. The use of policy-based governance approaches to embed accountability at the organisational level in a transparent way, provides opportunities to empower the independency of the legal agent and water guardian to ensure effective incorporation of ecological costs. Alongside this the inclusion of all types of value, monetary and non-monetary, embedded into investment decisions is vital to be able to reduce tension between policy and market-based mechanisms.

The efficacy of these mechanisms is strongly linked to the presence of actors to have influence over, if these fragment, as in the case of a Fortress World scenario, the governance mechanisms and the impacts of these also collapse. Conversely, if their role becomes redundant due to societal adoption of environmental protection attitudes and behaviours there is a risk of either complacency or failing to embed emerging understanding into ecological costs. These effects could be mitigated through the use of open and transparent data and visualisations to enable community engagement and empowerment.

Considering the systems maps, and CLD developed through this research the value ascribed to water, so often conflated with price, is clearly a critical component. Water bridges multiple roles, as a provider of both public and private goods as well as providing functionality within nature itself. These roles and the range of impacts that can be influenced by the water system are evident in the system maps which have been developed. However, this does not equate to water being valued: there is a perception of abundance (Duckett et al., 2024, Praskievicz, 2019) and widespread under-estimation of the amount of water consumed by individuals (Heino and Takala, 2015, Hunt and Shahab, 2021, Lucio et al., 2018). Indeed, visible and evident overexploitation increases public perception of value (Roobavannan et al., 2020), implying that once the impacts are observed there is a public willingness to protect water as a resource, until that point this inclination is suppressed. The environmental implications of this are stark as once habitats are degraded and biodiversity lost beyond a given point it becomes substantially harder for those losses to be recovered (Dasgupta, 2021). The governance mechanisms which have been proposed and assessed here against alternative future scenarios provide opportunities to embed the ecological cost of water services at an organisational level whilst enabling socially just outcomes for communities. System maps, visualisations and indicators have been integral to the development of these proposed mechanisms, moreover by enabling collaborative and transparent cross-societal engagement with the water system they support the future efficacy of these processes.

5.4 Pipebots – application of visualisations and indicators to incorporate environmental justice goals into assessing the case for change

Innovations have the potential to provide impacts across the water system (Section 5.1.5), the following discussion provides an assessment of a specific technological innovation using the tools developed within this study. Pipebots is a technology under development through an EPSRC research grant (EP/S016813 - Pervasive Sensing of Buried Pipes) which aims to transform the maintenance of pipe infrastructure, and particularly water networks, through the use of autonomous pervasive robots that assess pipe condition through the use of acoustic sensing (Bouch et al., 2023). This has potential benefits from an environmental justice perspective as it addresses issues connected to efficiency, leakage and CSO spills. These environmental consequences have intersections with social justice as the impact of mitigating CSO spills and associated disruptions falls disproportionately on some sections of society due to the regulatory requirement to pursue the lowest cost solution (this assertion is supported to comments made in semi-structured interviews– Section 4.4.3.2). Additionally, water resources within the UK are under increasing pressure due to the impacts of climate change resulting in changing weather patterns. Measures to reduce water consumption are ineffective whilst leakage rates remain high (Yonder (on behalf of CCW), 2022), effectively driving up the unit cost of water if alternative sources are utilised (for example desalination or extensive water transfers). Pipebots has the potential to facilitate the proactive management of networks at a lower cost per distance monitored, thereby enabling more extensive monitoring of the potable and sewer networks and enabling proactive management of issues before they become environmental and societal concerns. As such it provides a suitable test-bed for the tools that have been developed. Due to the pressing industry need for transformation the development of this technology is highly relevant. Moreover, understanding the case for change across the system with a view to future scenarios would be particularly pertinent to enabling adoption of a new technology.

5.4.1 System impacts of a technological innovation

The potential impacts of Pipebots on key relationships which support or restrict movement towards environmental justice can be assessed using multi-perspective system maps. The ecological perspective system map (Figure 5-7) highlights the potential to reduce harmful impacts from excess nutrient contributions related to point source discharges, thereby contributing to supporting environmental justice-led outcomes. This is achieved by reducing overflows through more effective and pervasive monitoring of sewer network conditions including the buildup of debris which could restrict flows.

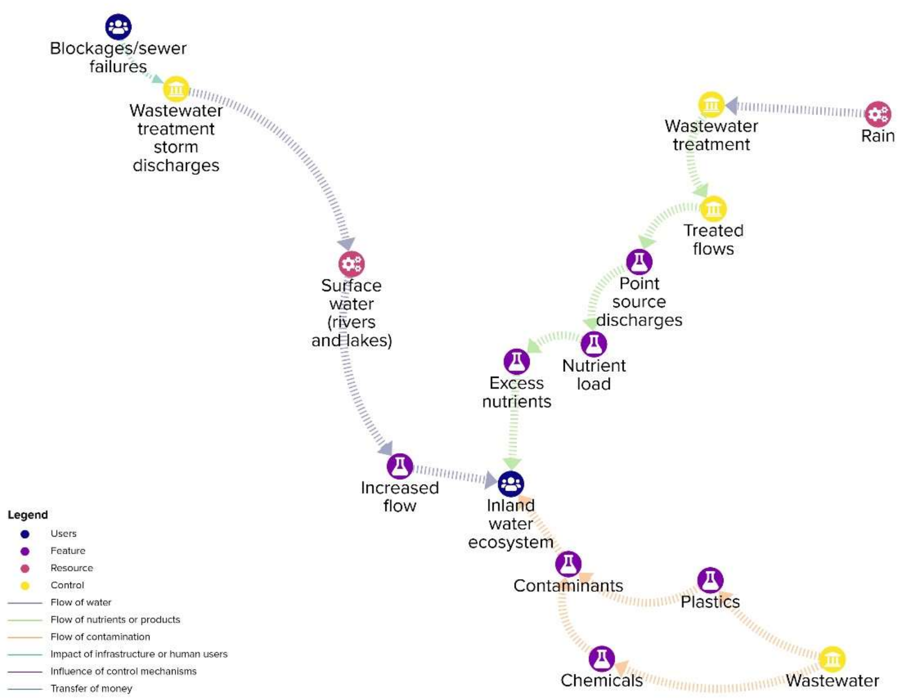


Figure 5-7: Environmental perspective system map showing only relationships impacted by implementation of Pipebots

From a societal perspective (Figure 5-8) the reduction of the impacts of rainfall leading to the release of pathogens in the environment would support public health outcomes. By protecting the management of effluent, Pipebots could contribute to the protection of the flow and quality of water thereby supporting blue green infrastructure with positive impacts on physical and mental health outcomes. Pipebots could support the reduction of leakage thereby increasing water efficiency and overall consumption thus supporting sustainable water provision.

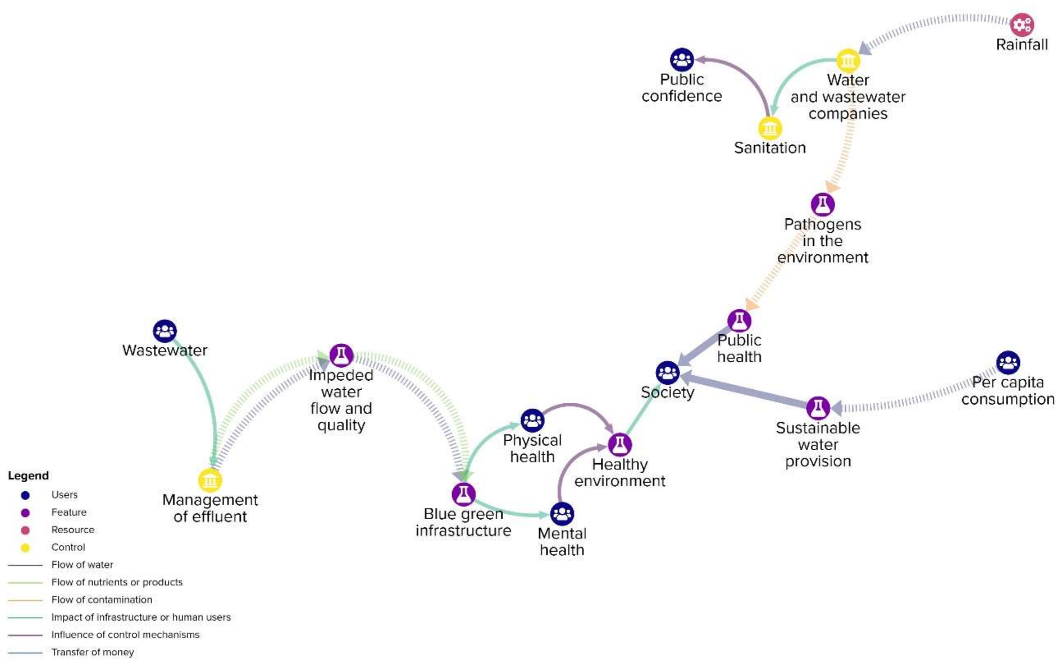


Figure 5-8: Societal perspective system map showing only relationships impacted by implementation of Pipebots

From an economic perspective (Figure 5-9) these functional relationships support the environmental solvency of the water sector and improved public service provision. These impacts combine to support the equity of outcomes and the success of the sector against an objective of ‘achieving the delivery of equitable public health outcomes through water and sanitation services for current and future generations’.

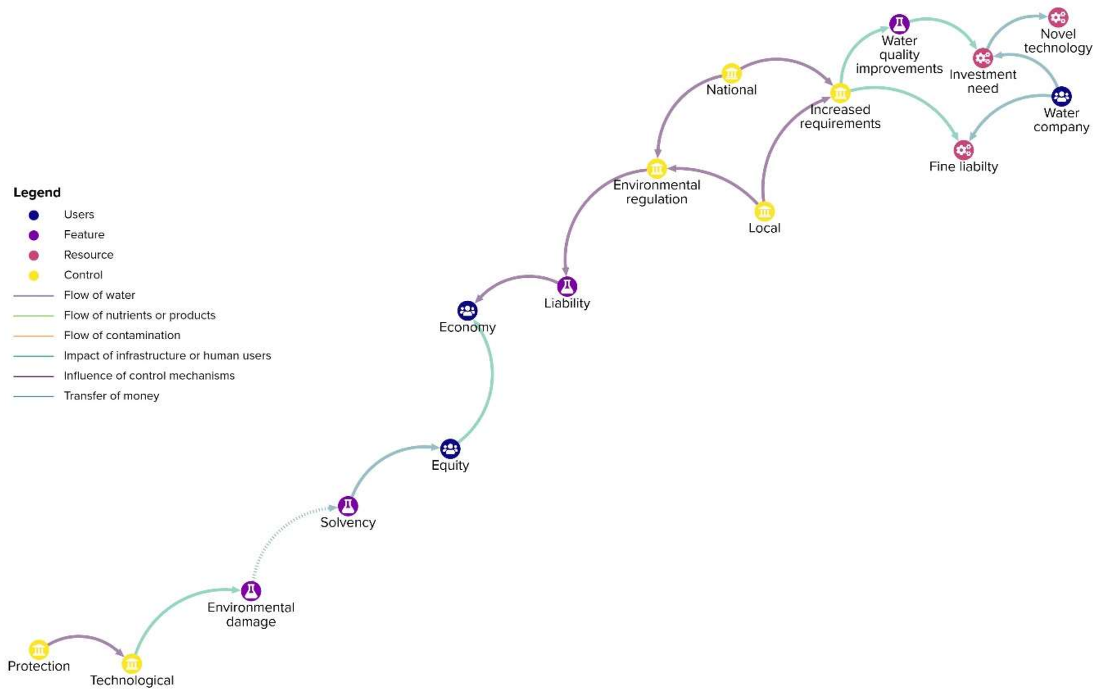


Figure 5-9: Economic perspective system map showing only relationships impacted by implementation of Pipebots

An assessment (Table 5-6) of the impact the implementation of Pipebots would have to the achievement of indicators developed in Section 4.4.5 demonstrates the far-reaching impacts of a single technology. The implementation of Pipebots has the potential to reduce the environmental impact of water and sanitation services through enabling proactive management of networks. This has ramifications across societal and economic indicators due to benefits from the provision of an improved environment and the value provided from payments for water services. Whilst not unique to Pipebots, the use of system maps and indicators makes this apparent supporting the development of a well-rounded case for change. The impact on affordability is indirect as water service providers may maintain the current level of investment in network assessments. However, they would be able to achieve additional coverage through the use of autonomous robots, thereby enhancing the service provided. Given the current public focus on CSO spills (see discussion in 4.4.3.2) and leakage (Yonder (on behalf of CCW), 2022) there is incentive for water companies to invest to mitigate these impacts. Pipebots would enable enhanced efficiency, either reducing additional costs associated with this investment, improving the efficiency of targeting investment proactively, or enabling the redirection of investment to deliver additional outcomes.

Table 5-6: Impact of Pipebots on indicators

Indicator	Impact	Interaction
ENV1	➦	Improvements to the proactive management of the wastewater network supports a reduction in CSO spills through the detection and removal of blockages leading to reductions in nutrient and contaminant discharges
ENV2	➦	
ENV3	➪	Pipebots is a precursor to enabling no-dig techniques for the repair and maintenance of water and wastewater networks.
ENV4	⟶	No expected impact
SOC1	⟶	No expected impact
SOC2	➦	Improvements to the proactive management of the wastewater network supports a reduction in CSO spills through the detection and removal of blockages leading to reductions in environmental pathogen levels
SOC3	➪	Enabling more targeted, proactive repair and maintenance of networks will reduce the associated disruption increasing well-being within communities
SOC4	⟶	No expected impact
ECO1	➦	Enabling proactive maintenance will lead to better value of services provided for equivalent costs
ECO2	⟶	No expected impact
ECO3	⟶	No expected impact
ECO4	⟶	No expected impact

Key:. ➪ – Indicator is supported, ➦ highly supported. ⟶ – Indicator is stable.

5.4.2 Considering future scenarios

Externalities are exerting pressure on the water sector, not least of which is a changing political climate and level of public engagement with water industry service provision. If new technological innovations, such as Pipebots, are to be considered a long-term prospect it is necessary to consider how they will align with potential changes in priorities into the future. Future scenarios, as a means to encompass potential socio-economic contexts, have been used to consider the requirements for implementation pertinent to adoption of Pipebots, including the framing of benefits within contexts with differing priorities.

Market forces

The high priority given to monetary processes in this scenario highlights the need to emphasise the economic case for change. Additionally, however, the ability to track and trade monetary benefits through market mechanisms is important as the 'buyer' would need to be able to track the benefits and 'bank' these benefits in order for it to be of value to them. This is possibly linked to a low-risk appetite for innovation and adopting new technologies, therefore the new technological offering would need to be de-risked to enable adoption and movement away from the status quo.

The benefits of implementing Pipebots would focus on de-risking the operation of extensive networks under changing climate conditions and mitigating negative press due to growing public distrust. Taking a wider perspective, it would contribute to the mitigation of environmental stress and may increase public satisfaction marginally. However, the main benefits case to influence adoption would relate to economic gains deriving from operational cost efficiencies; facilitating monitoring the same proportion of the network at lower cost or increasing the proportion of network monitoring coverage for the same cost with proactive action to minimise incidents in high-risk, high-impact areas.

Policy reform

This scenario encompasses a greater acceptance of risk combined with consideration of non-monetary value generation. However, the case for adoption of this technology is likely to be made through regulation, therefore the development of the case for change would need to target policy outcome objectives such as distributional equity, natural capital protection and environmental protection with economic growth.

The benefits of implementing Pipebots would include securing environmental and natural capital protection through reducing water resource use and reducing contamination from the operation of CSOs caused by sewer blockages. These benefits are fully achievable in a scenario that emphasises social and environmental standards, however concurrent and complimentary activity may disguise benefits hindering the calculation of benefits realisation and decreasing the ability to clearly demonstrate the benefits thereby undermining trust. There is also a risk of growing public distrust as a response to top-down policy approaches reduces public acceptance of autonomous robots with consequential reputational and property risk to the water service provider.

Fortress World

Within a Fortress World scenario innovation is very rare and limited to military purposes or to secure essential resources. Therefore, there may be a case for limited application amongst wealthy enclaves to protect water resources, in particular to protect the security of water resources and minimise risk of illicit connections. The business model and case for adoption would be required to appeal to the military, resource owners or wealthy occupants as centralised services are fragmented. Additionally, the case for adoption would be required to secure a quick and guaranteed return on investment to maximise monetary gain. The focus of adoption would be restricted to water supply applications in wealthy enclaves; therefore, the benefits are limited to security of supply of water. However, in this scenario water is an increasingly rare resource, particularly water of a quality which can be consumed. Therefore, although the extent of implementation would be limited the gains could be substantial, particularly if the user is able to maximise the financial gain of improved network reliability. This would result in impacts becoming limited to wealthy enclaves with limited overall benefit due to the fracturing of resources, infrastructure and society.

New Sustainability Paradigm

The New Sustainability Paradigm incorporates an innovation boom therefore Pipebots could be pitching within a competitive array of potential technologies and approaches. To stay relevant in this market, the Pipebots business model and offering would need to continue to innovate and develop. A movement towards material sufficiency would drive greater acceptance of products which are agnostic to the systems they interact with, such as data extraction methods and analysis systems including digital twins. There is also an emphasis on the embedded sustainability of materials, repair rate and energy required for operation in line with a collaborative effort to remain within planetary boundaries. Alongside this, a widespread emphasis on social and environmental equity and the benefits of non-monetary value generation abounds. Therefore, the case for adoption should be grounded in wider social and environmental values generated through implementation of Pipebots to support public good.

The benefits of implementation within this scenario are widespread and highly valued due to the high levels of social trust and cooperation. It should be noted that concurrent activity may disguise benefits hindering the calculation of benefit realisation, although with high social trust and overall positive environmental and social outcomes this may not be a large concern.

Implications for decision-makers

Decision-makers' internal priorities are likely to lie within the range of concerns illustrated in future scenarios and utilised in the analysis above. Therefore, to enable progression of the technology into production the case for change may be required to span these potential extremes to ensure that the framing is able to echo individual priorities to gain support. This would imply that the development of the case for change should encompass market opportunities in addition to social and environmental benefits, essentially making the triple-bottom line assessment apparent. In addition, the case for change should be able to demonstrate adaptability to future challenges and encompass agnostic interaction with supporting systems as well as component sustainability. Further to gaining decision makers' support, the case for change will be truly effective if it is also able to incorporate how public trust will be ensured under a range of attitudes and behaviours.

6 CONCLUSIONS

This study had the aim of creating tools to enable cross-sectoral and cross-societal knowledge communication regarding the water environment and its management. Specifically, it aimed to address the following research hypothesis:

VISUALISATION TOOLS ARE AN EFFECTIVE MEANS TO PRESENT INFORMATION AND KNOWLEDGE ENABLING CONSIDERATION OF FUTURE CONDITIONS, INCLUSIVE DECISION MAKING AND SOCIETAL AGENCY IN THE MANAGEMENT OF THE WATER ENVIRONMENT.

Considering historic trends demonstrates how policy, behaviour and technological influences have influenced the management of water services. Existing decision-making methods were analysed on the basis of the goal they strive towards and how they look to the future, identifying a need to transparently represent relationships within a system both to engage a variety of actors and allow interrogation of the system.

This led to the definition of the boundary as a surface water system within the context of the water sector within England and Wales; a delineation which enabled consistency in the current policy and regulatory framework. Further to this, a goal of environmental justice was determined, which reflects a requirement to represent human and non-human users of the water environment whilst also providing recognition of ingrained injustice, and potential for injustice, in the management of the water environment. It is notable that within regulatory systems the inclusion of justice themes is implicit rather than explicit. The tools developed herein provide a mechanism to recognise environmental justice within the water system more fully and overtly.

Focus group discussions provided validation for the premise of the research to combine environmental and social requirements through consideration of environmental justice as a goal. They also supported framing the analysis on the water system as opposed to administrative boundaries due to these latter boundaries forming a barrier for collaboration and creating opportunities for social injustice. Furthermore, they supported the use of visualisations as a means to communicate complex issues.

Evidence-based system maps were developed to consider the relationships within the surface water system, these maps were generated from environmental, societal and economic perspectives to facilitate analysis. The relationships within each system map were characterised based on whether they were supportive of, or destructive to, the ability to thrive under a definition of environmental justice. Developing the system maps within an open, collaborative platform creates opportunities for further development for specific geographies enabling greater nuance to be represented through collaborative discussion with local agents. The system maps have been fundamental to developing further tools as part of this study, however they are also valuable in their own right as a mechanism for enabling localised collaboration. As such there are opportunities to create bespoke system maps, through participatory development, which reflect specific relationships and concerns within a waterbody or operational catchment.

The surface water system is subject to changing conditions, and as such it is necessary to consider how relationships within the system react. These assessments were undertaken using future scenarios to enable consideration over the full duration of an intervention's potential implementation, and over the timescales at which environmental change as a result of interventions may be observed. These socio-economic frameworks have been developed at the global scale and adopted within urban redevelopment research; representing plausible extremes they allow the user to consider conditions which are removed from the current situation. A STEEP framework was used to translate global scenarios to the surface water system scale within the UK. These attributes were embedded within the system maps illustrating how changing socio-economic structures would impact the ability for the system to thrive. This served to highlight the range of impacts across the system as a result of changes in policy, social norms and technological approaches.

The resulting, highly detailed, multi-perspective system maps incorporate and allow interrogation of the complexity of the system. This also has the consequence of creating difficulties in analysing the system for more strategic purposes. Therefore, the key points of interaction across perspectives and future scenarios were identified, becoming the central points in the development of a conceptual model incorporating reinforcing loops centred on value and cost recovery, product generation and urban development. Central to this model are relationships associated with behaviours, attitudes and policies that closely relate to social justice issues and reflect the impact human interaction has on the natural water environment. Creating understanding of these relationships and impacts has allowed visualisation of areas of potential intervention and innovation. This has been used to visualise the impacts of a justice-led policy intervention, demonstrating how such an intervention has the potential to influence critical pathways.

Generating understanding of relationships and influencing factors provides a structure for analysing impacts; this is enhanced through the use of indicator systems to identify points of intervention which are assessed against common criteria. An environmental justice-led approach to the assessment and development of indicators has been formulated and applied.

This has ascertained that existing indicators did not fully specifically address the objective of environmental justice. This does not invalidate the use of these indicators, instead it highlights that in this form they do not enable an assessment of environmental justice across the realms of environment, society or the economy. The approach taken to the development of an indicator system was validated through use of a questionnaire and subsequent semi-structured interviews. This process, which incorporated expert views from across the UK water sector, provided corroboration of the approach as well as the role of visualisations and an environmental justice-led approach to enabling improved management of the water environment. Notably the discussions provided evidence of the lack of impact which the 25-year environment plan is providing both within grassroots movements and statutory requirements, including discontent that this was the case. Consequently, it could be considered that there is a requirement to improve the incorporation of future scenarios into policy frameworks and there is an associated appetite across the industry for this to occur. A second notable output from semi-structured interviews was a discussion of trust across the sector, in particular societal trust over the delivery of water as a public good. There was recognition of the need to rebuild trust including a particular requirement for third parties to bring independency, mediation and scrutiny using accessible information. This relates directly to the outputs of this study.

Outputs of the validation process were combined with an analysis of the available data at a suitable level of granularity to ascertain the requirements of an indicator system and the constraints on data availability to utilise within such as system. This analysis, alongside the environmental justice-led approach developed through system mapping, was used to propose an indicator system. Consisting of twelve indicators across the perspectives of environment, society and the economy each indicator has been defined along with a benchmark, visualisation criteria and a healthcheck. The healthcheck is a novel approach which serves as a mechanism to ensure data analysis is accompanied by an appropriate level of corroboration with additional data sources, thereby facilitating the incorporation of local knowledge and citizen science into the formal assessment. The purpose of this stage is to enable the data to be challenged constructively and collaboratively to increase cross-societal acceptance of the outputs and agency within the community. Implementation of the proposed indicators at operational catchment and waterbody scales demonstrated the ability of these indicators to enable visualisation of status from multiple perspectives within an environmental justice-led framework. Evaluation of the impacts of potential future socio-economic contexts on these indicators provides insights into how future scenarios may unfold with respect to environmental justice outcomes within a surface water system. Specifically, this enables areas of sensitivity and heightened risk to be identified and provides opportunities for mitigation to be put in place.

Exploring the outputs of the research objectives within different tiers of practice has demonstrated that at the system scale there is potential to identify needs and understand how these needs may be subject to varying pressures into the future. Providing insights such as these enables the consideration of interventions with greater awareness of requirements for adaptability. Incorporating a place-based systems approach enables the evaluation of governance approaches from multiple perspectives, in this case water pricing mechanisms. This analysis has highlighted the role of policy in the implementation of market processes to ensure the duality of water as a public good and an economic good is reflected and justice-principles underpin the foundation of such measures. Finally, application of these tools to a technology under development has enabled an assessment of the potential benefits of this technology and its interactions within potential future scenarios. This is because future scenarios not only reflect the potential range of extremes in socio-economic contexts, but also the range of priorities within decision makers who may, in turn, favour markets, policy, individualistic or egalitarian approaches. As such, understanding the potential benefits and considerations within future scenarios may enable the development of a case for change which can reflect this wide range of priorities.

There is industry support for greater transparency across the sector, as evidenced by discussions within semi-structured interviews, with views expressed across various individuals from differing parts of the sector. The Rivers Trust Sewage Map has demonstrated the ability for accessible information, in an interactive map, to raise public awareness and gather momentum for action. However, this represents a single-issue within a complex system. The visualisation tools and indicator system developed within this study would enable the complexity of the system to be communicated more fully. Whilst the basis of visualisation tools has been represented within this study, further development is required to embed this approach within an open and transparent platform that can be used and interrogated by cross-sector actors. Discussions within the semi-structured interviews highlighted an appetite to embed the findings of this study within the sector. This would create a platform for cooperation on complex issues, enabling collaboration and societal agency over the actions undertaken within the water system. Further to this, the ability to visualise and increase the accessibility of information regarding surface water systems using a place-based approach, by increasing societal involvement, increases the value ascribed to surface water systems.

It is therefore considered that the outputs of this study demonstrate the potential of using visualisations and indicator systems which are grounded in an environmental justice-led approach to enable effective decision-making and societal agency in the management of the water environment. To embed and further develop these approaches several recommendations have been made:

- There is evidence and recognition that environmental justice is a relevant concept within the water sector and as such, explicit reference should be made to this within regulation and governance systems. The visualisations and conceptual model that have been developed enable evidence-based societal, environmental and economic impacts to be analysed through a justice lens. It is suggested that this provides a basis for consideration and embedment of an environmental justice-led approach across the water sector.
- The system maps developed as part of this study should be developed through a place-based and participatory approach to incorporate geographical specifics to enable a more detailed and localised characterisation.
- Implementation and analysis of the indicator system using participatory methods would enable assessment of the efficacy of this approach in enhancing collaboration and trust over outputs.
- The system maps hold the potential to create the basis of value calculations; utilising this as a framework could enable the development of financial mechanisms that are inclusive, transparent and grounded in justice approaches.
- The system of interest within this study is surface waters, therefore coastal communities and estuarine waters are not incorporated. Further development would

be required to expand assessments for application in such areas, including a specific review of justice considerations within these areas. Additionally, the assessment could be further developed to incorporate groundwater and the unique considerations involving groundwater that have not been included herein.

It can be concluded that this study has furthered the ability to present information and knowledge through the development and application of visualisation tools. The ability of these tools to enable inclusive decision-making has been demonstrated through application at multiple tiers of practise. Whilst it has not been possible to directly assess the impact on societal agency, the impacts of single-issue interactive maps suggest that this is a possibility. When combined with sector interest in incorporating environmental justice-based indicators developed herein to an open, independent platform, this provides confidence that these tools would support increased societal engagement, leading to greater societal agency over outcomes within the water environment.

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