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What water supply system research is needed in the face of a conceivable societal collapse?

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ABSTRACT

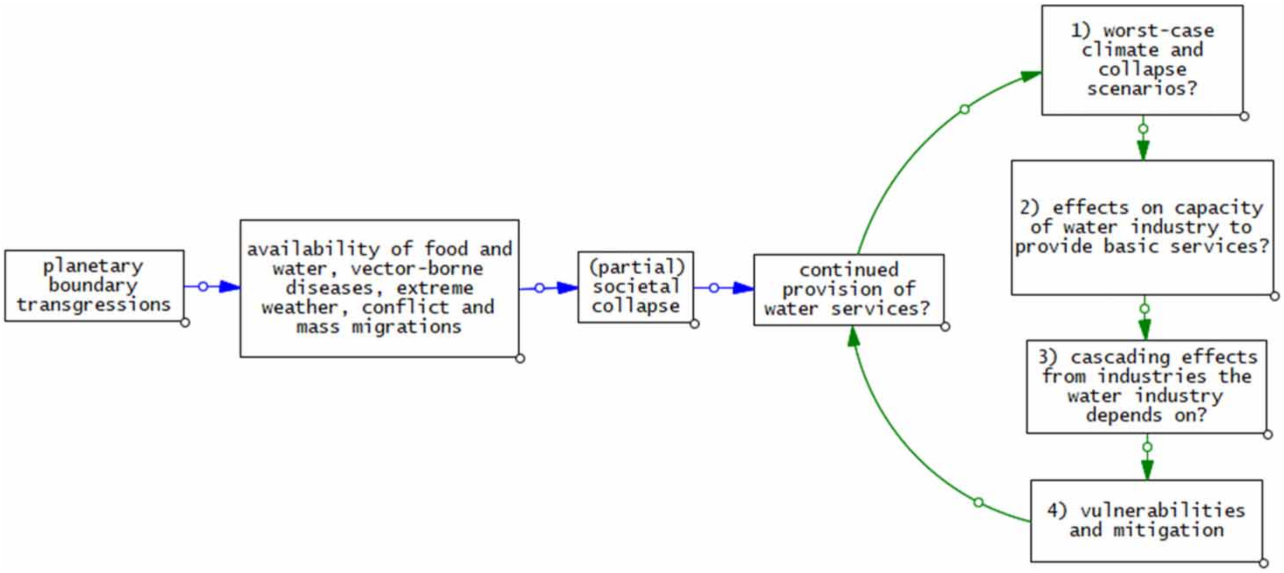
The world grapples with immediate crises like COVID-19, Russia's invasion of Ukraine, floods, droughts and wildfires. However, a longer-term crisis looms due to humanity's overstepping of planetary boundaries and its disruptive consequences. Growing awareness of the potential collapse of societies due to planetary boundary violations has prompted increased attention in the scientific literature. In the water sector, where infrastructure built today might persist during a future collapse, we must therefore ask ourselves how a (basic) level of water supply can be maintained in a collapsing society. This paper explores this question and proposes research directions to address it in the short to medium term. Despite the seeming remoteness of a societal collapse scenario, it is imperative to incorporate it urgently into water infrastructure research and planning.

Key words: deep adaptation, risk matrix, societal collapse, water infrastructure, water supply

HIGHLIGHTS

- Environmentally induced societal collapse is an ignored risk for the water sector.
- Research into potential consequences and strategies for deep adaptation are needed.
- A four-stranded approach for this research is proposed, mirroring a prior one for research on worst-case climate change and systemic risks.

GRAPHICAL ABSTRACT



INTRODUCTION

As the world continues to attempt to deal with short-term, high impact, crises, such as the COVID-19 pandemic, Russia's invasion of Ukraine, floods, droughts and wildfires, a longer-term crisis is arguably looming, which is associated with mankind's transgression of planetary boundaries (Rockström *et al.* 2009) and the resulting highly disruptive effects this could have on our societies. The planetary boundary concept aims to describe the boundaries of safe operating space for humanity. To start with the planetary boundary of our climate, for which we are presently considered to be in the zone of uncertainty and increasing risk (Steffen *et al.* 2015), current policies are considered insufficient to meet the 2 °C or even 1.5 °C targets of the Paris Accord – we are heading for a 2.7 (2.2–3.4) °C increase by 2100 (Climate Action Tracker 2023) instead. Other planetary (sub)boundaries – biosphere integrity, novel entities, biogeochemical flows, land system change, green water and regionally blue water – are already considered to be transgressed (Steffen *et al.* 2015; Richardson *et al.* 2023 and references therein).

The possibility of societal collapse resulting from planetary boundary transgressions, potentially pushing Earth-system components beyond tipping points, is gaining serious attention in the scientific literature (Brozović 2022). Lenton *et al.* (2019) examine the climate planetary boundary and assert that 'If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization.' Recent updates to thresholds for various climate tipping points indicate an increased likelihood of occurrence even with a 1.5 °C mean global temperature rise (Armstrong McKay *et al.* 2022).

Bologna & Aquino (2020) and Aquino & Bologna (2021) look at the relationship between population growth and deforestation and conclude that a catastrophic population collapse is possible or even likely. Indeed, countless societies have collapsed in mankind's history (Motesharrei *et al.* 2014) due to stresses of varying kinds (including regional climate change) on a local or regional scale (Brovkin *et al.* 2021). Planetary boundary transgressions exert pressure on societies in particular through their impact on the availability and distribution of food production (e.g. more irregular weather, changing crop cultivation zones, marine ecosystem collapse; IPCC 2022), the availability of water (for drinking and irrigation; IPCC 2022), vector-borne diseases (IPCC 2022; Kemp *et al.* 2022) and extreme weather (a.o. the increased incidence of deadly wet-bulb temperatures; Saeed *et al.* 2021). Indirectly, these stresses may lead to conflicts and/or mass migrations (CNA Military Advisory Board 2007; Unfried *et al.* 2022). These interdependencies have been described in a causal loop diagram by Richards *et al.* (2021).

Kemp *et al.* (2022) argue that climate change could have catastrophic consequences, even at modest levels of warming, and understanding extreme risks is crucial for decision-making and emergency response preparation. They propose a 'Climate Endgame' research agenda that offers a way to explore worst-case scenarios and systemic risks associated with climate change.

This paper argues that the catastrophic potential consequences of climate change need to be studied in the context of the water industry as well. As such, it attempts to provide a translation of the ‘Climate Endgame’ research agenda to water research. So far, the drinking water literature has failed to consider societal collapse scenarios, focusing exclusively on conventional projected environmental changes – ignoring potential societal cascading effects – and addressing challenges with established adaptation approaches (e.g. Mishra *et al.* 2021). Because of the long asset lifecycle and planning horizon for water supply infrastructure, it is, however, conceivable that the infrastructure that is built today will still be in service during a possible collapse occurring sometime later this century. As our societies and indeed our livelihoods depend so strongly on the provision of drinking water of adequate quality and in adequate quantities, and as our water supply systems continue to become more complex and dependent on high-tech solutions, we must ask ourselves how a (basic) level of water supply can be maintained in a collapsing society. Because of the deeply uncertain nature of the processes involved, a possibilistic rather than a probabilistic approach is more meaningful.

CONCEIVABLE SOCIETAL COLLAPSE

Kemp *et al.* (2022) define societal collapse as ‘significant sociopolitical fragmentation and/or state failure along with the relatively rapid, enduring, and significant loss [of] capital, and systems identity; this can lead to large-scale increases in mortality and morbidity.’ What is important here is the observation that the relapse is of a long-term nature; this contrasts with disasters after which (re)construction takes place either to the original state or to a new state that is better adapted to changed conditions (Gallopín 2006).

In many cases, (rapid) economic, (socio)political and demographic aspects of a downturn are closely related. A good example is the Arab Spring, in which protests over food prices led to political upheaval (and in the case of Libya, a degree of collapse). The timescale and degree of collapse and the geographical extent can vary. Several examples from modern history show that local and regional factors often play a decisive role. A particularly relevant example is the dramatic decline in the supply of drinking water by up to 40% in Syria over the past decade due to damaged infrastructure, maintenance prevented by the circumstances, lack of spare parts and loss of technical staff (ICRC 2021).

RISK PERSPECTIVE

From a risk perspective, the argument that the societal collapse scenario should be considered seriously by the water industry is unavoidable. The commonly used 5 × 5 risk matrix approach (e.g. NASA 2017) is illustrated in Figure 1. This shows the risk as the product of (estimated) likelihood (rows) and impact (columns). We propose to add an additional column – existential impact – though it is questionable whether the associated numerical value suffices. Figure 1 shows that, depending on one’s assessment of its likelihood (which we do not know), societal collapse should be considered a moderate (collapse is ‘rare’) to extreme (beyond ‘unlikely’) risk for any water sector entity.

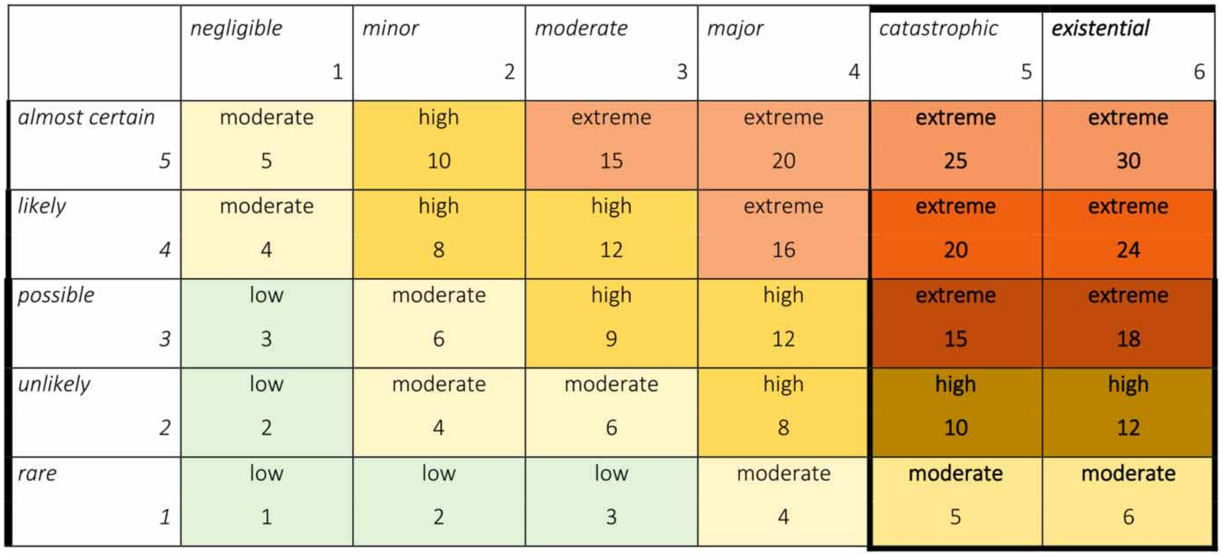
CONSEQUENCES OF COLLAPSE AND CONTINUATION OF WATER SUPPLY

This existential issue can only be thought of meaningfully in terms of minimizing suffering by securing the supply of water as much as possible under difficult and deteriorating conditions. Some insight into what the impact of such a scenario might be on water companies and their social role can be gained by studying water supply and infrastructure in fragile and conflict areas. Bolton (2020) mentions several vulnerabilities (interpretations in the context of the stresses described above added by the authors of the present paper):

(1) increase in water demand from displaced people: climate refugees fleeing extreme weather, sea-level rise or social decline; or decrease in water demand as inhabitants flee extreme weather or rising seas;
(2) departure of qualified (technical) personnel: themselves fleeing from deteriorating local conditions;
(3) physical damage to the infrastructure: collateral damage or deliberate sabotage or theft;
(4) reduced availability of electricity: due to similar processes (2, 3, 5, 6, 7);
(5) erosion of the financial sustainability of water companies: increased non-payment and/or water theft; (partial) failure of the financial system.

Further effects can be imagined by considering additional external dependencies in more high-tech water supply systems:

(6) reduced availability of (high-tech) components and chemicals: decline in production, transport, trade and financial services, partly through similar mechanisms (2, 3, 4, 5);



	negligible 1	*minor* 2	*moderate* 3	*major* 4	*catastrophic* 5	***existential*** 6
almost certain 5	moderate 5	high 10	extreme 15	extreme 20	**extreme 25**	**extreme 30**
likely 4	moderate 4	high 8	high 12	extreme 16	**extreme 20**	**extreme 24**
possible 3	low 3	moderate 6	high 9	high 12	**extreme 15**	**extreme 18**
unlikely 2	low 2	moderate 4	moderate 6	high 8	**high 10**	**high 12**
rare 1	low 1	low 2	low 3	moderate 4	**moderate 5**	**moderate 6**

Figure 1 | Risk matrix approach to conceivable societal collapse.

(7) (partial) breakdown of data and communication infrastructure: partly through similar mechanisms (2, 3, 4, 5, 6);
(8) contamination of sources by reduced security or containment of chemical or nuclear products or waste materials through mechanisms (2, 3, 4, 5, 6, 7) that may consequently spread via water or wind.

An overview of these processes and their interdependencies is presented in Figure 2 in a conceptual causal loop diagram. The elaboration of quantitative descriptions of relations and interactions, for example in a system dynamics framework (Randers 2000), will facilitate the quantitative evaluation of the interdependencies.

Diep *et al.* (2017) draw lessons from various crises in the Middle East and North Africa. They advise water companies to build their resilience, which is characterized by flexibility, resourcefulness and responsiveness, redundancy, modularity and safe failure. These are already part of existing approaches for disaster resilience but obtain a new dimension when considered from the perspective of a conceivable societal collapse. As an example of this, we mention the ongoing upscaling and digitalization of the water industry and water supply systems. While these in themselves can bring many gains in efficiency, insight and resilience of water supply systems, the entailing of increased complexity and interdependencies also seem to constitute a vulnerability of water supply from the perspective of a conceivable societal collapse.

RESEARCH TOWARDS A COLLAPSE-RESILIENT WATER SUPPLY SYSTEM

Kemp *et al.* (2022) propose a four-strand research strategy for catastrophic climate change:

1. understanding extreme climate change dynamics and impacts in the long term;
2. exploring climate-triggered pathways to mass morbidity and mortality;
3. investigating social fragility: vulnerabilities, risk cascades and risk responses;
4. synthesizing the research findings into 'integrated catastrophe assessments.'

How can this agenda be translated to water supply systems research? We propose the following:

1. The water industry needs to recognize that there is a significant amount of uncertainty that is explicitly stated in climate projections, but also a significant amount of uncertainty that is not, including climate tipping points (for which the major mechanisms are currently not well resolved in global circulation models; Hewitt *et al.* 2022; Stocker 2023). A good example is the possible shutdown of the Atlantic Meridional Overturning Circulation, which would make northwestern Europe significantly colder and redistribute precipitation (Jackson *et al.* 2015). Though stable in many models (Liu *et al.* 2017), evidence is overwhelming for its historical variations and mounting for its possible current instability (Boers 2021; Ditlevsen & Ditlevsen 2023). Therefore, in addition to considering the IPCC's RCP/SSP (Representative Concentration Pathways/Shared Socioeconomic Pathways) scenarios or their derivatives, we need to construct together with climate scientists an informed set of additional scenarios of high impact and *unknown* (rather than the commonly used

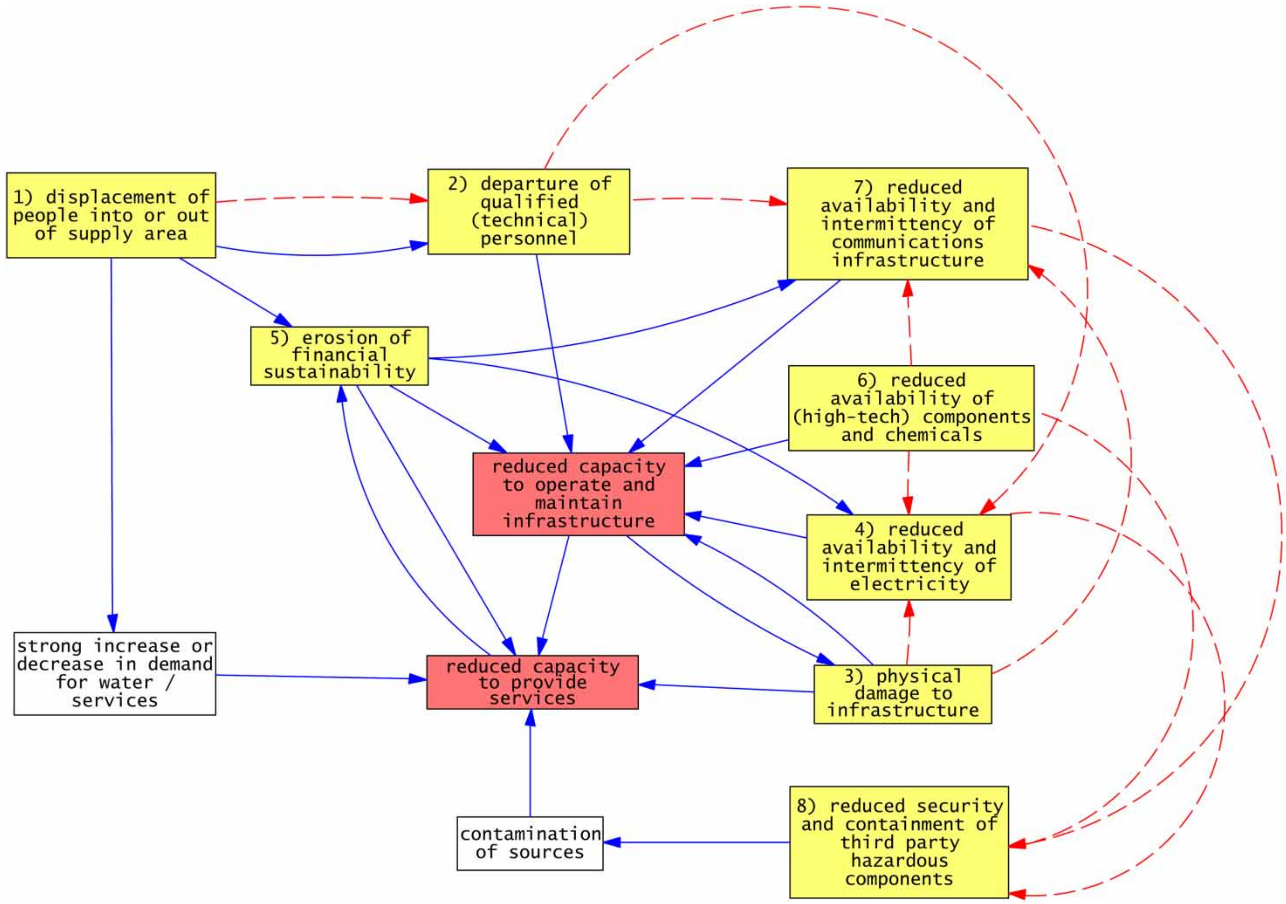


Figure 2 | Causal loop diagram for the effects of partial societal collapse on water services. Exogenous root causes are indicated by yellow boxes. Blue/solid arrows indicate effects within the water industry. Red/dashed arrows indicate relevant parallel effects outside the water industry that may impact the water industry (non-exhaustive).

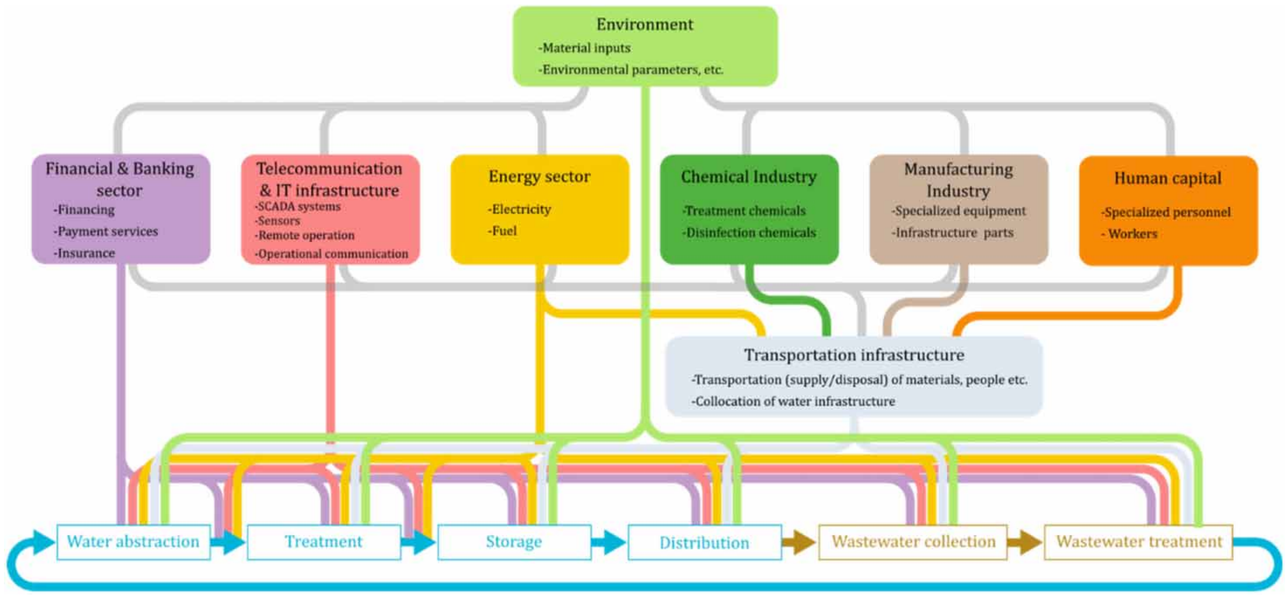


Figure 3 | Simplified web of dependencies for water supply systems.

adjective *low*) likelihood and use these to develop and test water supply system resilience associated with all known climate tipping points (Armstrong McKay *et al.* 2022) with a non-stationary response of the hydrological cycle (Burgan *et al.* 2017; Chebana & Ouarda 2021).

2. Research should be formulated to address the question of how the direct effects of climate change, in particular famine and undernutrition, extreme weather events, conflict and vector-borne diseases (Kemp *et al.* 2022), affect both the demand for water and the capacity of the water industry to provide basic services (drinking water and sanitation) at a sufficient level (quality and quantity). Observations and understanding derived from current and historical conflict and disaster areas can provide a basis for extrapolation.
3. Complementary to these issues, research should also be directed at understanding how cascading effects potentially resulting in systemic crises affect the capacity of the water industry to provide basic services. This means that in addition to the expanded set of physical scenarios mentioned under the first point, we need to develop a comprehensive set of social scenarios that present a range of plausible societal outcomes from these physical scenarios.
4. When we map out the dependencies of our water supply systems in terms of materials, components, energy, data, skills, etc. (qualitative illustration of the different external dependencies of water supply systems is shown in Figure 3), including the nature and quantification of different interactions, these social scenarios can be used to analyze the vulnerabilities that stem from these (an overview of suitable approaches is provided by Ouyang (2014)). Deep adaptation strategies can be devised to mitigate these vulnerabilities.

CONCLUSIONS

A (partial) societal collapse as a consequence of mankind's continuing transgression of planetary boundaries has started to receive serious consideration in the scientific literature. Our paper argues that consideration of this scenario in long-term planning by the water industry is essential. Because of the long asset lifecycle and planning horizon for water supply infrastructure, it is conceivable that the infrastructure that is built today will still be in service during a possible collapse occurring sometime later this century. Research into the potential consequences and strategies for deep adaptation, for which we propose an agenda, is both necessary and timely.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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