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# Scenarios of water extremes: Framing ways forward for wicked problems

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## 1 | EMERGING 'WICKED' PROBLEMS

Following particularly dry years causing droughts in many parts of the world, several countries worldwide have been affected by floods in July and August 2021. Some of these were catastrophic, causing deaths and widespread damage. These floods came with a cascade of side effects, such as the destruction of wastewater treatment systems and chemical infrastructure, causing the contamination of rivers by various pollutants including sewage overflows and spills of hazardous substances. This yields long-term negative effects on social-ecological systems (Doocy et al., 2013).

These events have illustrated that water extremes such as droughts, floods, and—as we argue—water pollution, are complex and uncertain events. We argue that these extremes will present new, interdependent problems characterized by uncertainty that are not easy to address and that require new approaches to anticipate and cope with. Therefore, we asked during an international expert workshop: How can we more adequately address the complexity and uncertainty of water extremes in scenario analysis?

The uncertainties and complexities associated with future water extremes do characterize these extremes as emerging wicked

problems (Kirschke & Kosow, 2021). Floods, droughts and pollution are characterized by interconnected phenomena, drivers, and impacts (see Figure 1). At the level of *phenomena*, interconnected droughts have especially severe effects and flood and drought can appear in close sequences. Also, drought and flood both can have impacts on pollution levels (Hannah et al., 2020), for instance on the nutrient concentration of rivers, through the use of substandard reclaimed water in dry areas, and through the mobilization of pollutants or discharge of untreated wastewaters in case of floods (Hrdinka et al., 2012). Future extremes are influenced by multiple *drivers* such as climate oscillation and hydroclimatic change, population growth, economic activity and land use, but also technological change (e.g., ageing infrastructures), ecosystem alteration and buffering capacity. These drivers interact, also through teleconnections. Future water extremes pose multiple social, economic, and ecological risks. They have *impacts* on human health, the economy, agriculture, ecosystems, and on water conflicts and migration, just to name a few domains. These impacts also influence each other. In addition to complexity, there is uncertainty: future developments of drivers and their effects on extremes are at least in part open (uncertain)—and also depend on what we decide and do today. The same holds true for the extent and degree of future impacts.

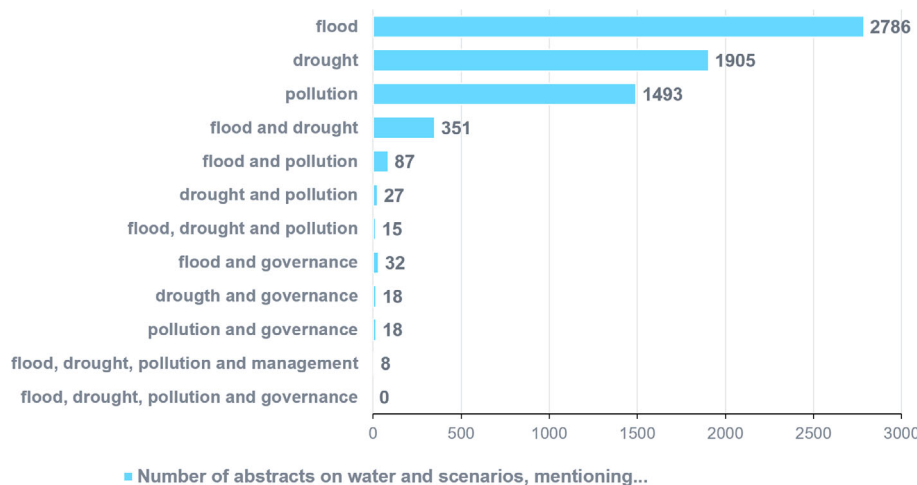
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**FIGURE 1** Water extremes as emerging wicked problems

### Emerging wicked problems



**FIGURE 2** Overview on number of articles with reference to scenarios and to water extremes (Web of Science core collection, 01.01.2010–01.12.2021, articles in English, search in abstracts, AB = (water AND scenario\* AND ...)

## 2 | CURRENT SCENARIOS OF WATER EXTREMES

Future water extremes are typically conceptualized in the form of scenarios. Scenarios are alternative pictures of possible futures and the pathways leading to them. It is important to note that they are not ‘future presents’ (Grunwald, 2014) but ‘present futures’, that is, today’s assumptions on how future developments plausibly could look. One can distinguish predictive, exploratory and normative scenarios (Maier et al., 2016). Scenarios are often based on modelling, qualitative storylines, or on combinations of both (Elsawah et al., 2020). They are developed and used to make sense of the complexity and uncertainty of the future (see e.g., Haasnoot & Middelkoop, 2012). They are meant to assist decision-makers at local to global scales to design and implement policies to prevent and to adapt to negative effects of water extremes such as droughts, floods, and pollution.

However, are current scenarios sufficient to help decision-makers to address extremes? Studies to explore the future status of water resources have been developed since the 1970s. Since then, scenario

studies anticipating the possible futures of floods and droughts and also pollution have been conducted. The Web of Science database (2010–2021) gives a broad overview on the current state of research on scenarios of water extremes (see Figure 2). This overview leaves out grey literature, i.e. also the important use of scenario studies in statutory planning processes, and also publications in other languages than English. These metrics show that there is a large number of studies from academia on the future of water extremes.

However, scenario studies formulate specific assumptions on the future and are based on choices to emphasize some aspects and scenarios but to neglect others. Our search for abstracts covering the topics of scenarios and of extremes supports anecdotal evidence that existing scenarios are limited in their scope, with three key limitations:

- Far more research deals with water scenarios considering ‘floods’ or ‘droughts’ rather than ‘pollution’.
- Water scenarios often examine individual extremes rather than their complex dynamics. There is, in particular, little research specifically looking at both water quantity (‘flood’ and/or ‘drought’) and water quality phenomena (‘pollution’).

- Very few abstracts mention ‘management’ or ‘governance’ linked to the two types of extremes.

### 3 | TOWARDS BETTER SCENARIOS OF WATER EXTREMES

Better knowledge about potential mitigation of, and adaptation to, the impacts of extreme events will remain a key topic in water research, specifically in the context of climate change, sustainability and resilience. But what can scenario researchers and research policy do better in the years to come? How can they more adequately deal with the complexity and uncertainty of water extremes to construct more useful scenarios? Figure 3 summarizes our key points.

#### 3.1 | Advance research on interlinkages

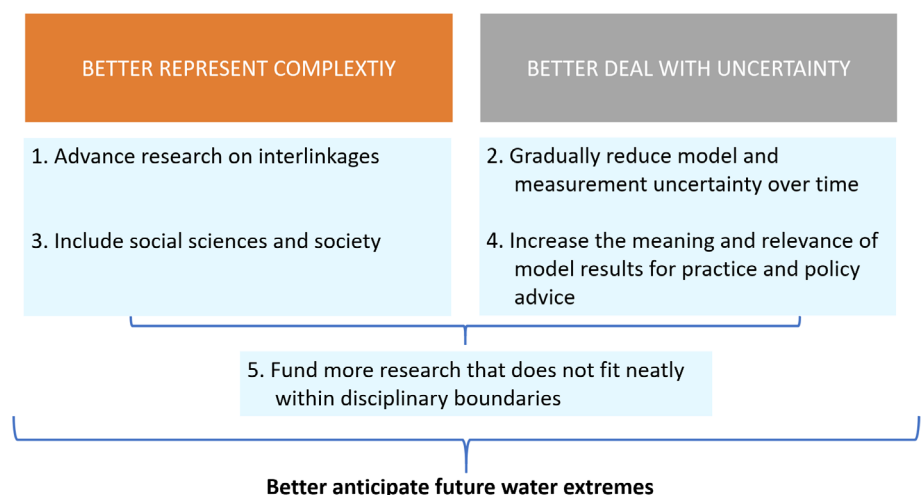
Water extremes are complex phenomena, but this complexity is hardly considered in present scenarios. To prepare for the future of water extremes, we need scenario studies (i) combining floods and droughts *and* water pollution, and (ii) exploring their relationship over time. Thus, scenario research may shift to compound events as drought-flood sequences and to the linkages between droughts/floods on the one hand and pollution on the other. These scenarios should also consider different water types, such as groundwater, which can serve as a buffer zone, or treated wastewater, which can provide additional water resources during drought. Due to the interlinkages of water extremes to multiple drivers and impacts, there is also a need for ‘water PLUS’ scenarios, as considered in sectoral or resource nexus perspectives (e.g., water-energy-food or a water-soil-waste nexus). Sometimes water related problems (e.g., droughts) are better ‘solved’ outside the water sector (e.g., by changing cropping patterns in agriculture instead of searching for new water), and for this to become visible, the scenarios need to show the links between sectors and possible governance strategies and policies.

#### 3.2 | Gradually reduce model and measurement uncertainty over time

Recognition of the value of science is crucial to the continuing functioning of a progressive society. Societies increasingly rely on monitoring and modelling not only to anticipate extreme events, but also to inform deliberation about countermeasures, to prepare for and adapt to water extremes and to increase resilience. Maturity, robustness, limitations and uncertainty of both models and measurements need to be clearly and transparently communicated in a way that is easy to understand (Guillaume et al., 2017) to ensure expectations are set appropriately and support trust in science. Investment in improved measurement and reduced model uncertainty need to be planned to anticipate needs as they emerge. Examples of current research and development opportunities include more real time monitoring data, data standardization, the integration of improved numerical weather forecasts and the interoperability and linkage of meteorological and hydrological models to civil protection protocols, as well as open information channels to inform the population at risk. Uncertainty will always remain (including unknown unknowns), especially if we broaden the scope of models, for example, by considering interlinked aspects as highlighted above. Therefore, the question is, what degree and what kind of uncertainty can we accept, and how do we facilitate conversations with stakeholders to ensure uncertainty is managed legitimately?

#### 3.3 | Include social sciences and society

Water extremes affect humans in various ways. Likewise, humans affect water extremes in various ways, starting with their impacts on drivers such as climate change and the design of mitigation and adaptation options. Thus, solely building scenarios is not sufficient to inform and strengthen adaptation and resilience. The transfer of the ‘orientation knowledge’ provided by scenarios into ‘transformation knowledge’ and finally into practice requires exchange (i) with social science research and (ii) with society. Exchange with social science



**FIGURE 3** Summary overview on key recommendations to better anticipate future water extremes

research implies several dimensions: one is representation of society in water scenario studies—social drivers as well as impacts of water extremes on society. Another is improving the linkage of governance and public policy research and its knowledge on policy design and implementation with natural science dominated scenario analyses on water extremes. Improving this linkage could also help to better understand how national and international bureaucracies and their partners in the respective governance arrangements can become capable of understanding and dealing with both rapid onset events (e.g., river flooding or pollution in consequence of catastrophic events) and slow onset events (e.g., sea level rise or constant but accumulating pollution; Tosun & Howlett, 2021). In scenario processes, exchange with society, that is, actors outside of academia, allows consideration of societal contexts, needs, and requirements. This is best approached through participation and co-production rather than linear transfer of knowledge (Chambers et al., 2021). Co-production is an essential approach to increase the meaning and relevance of model results for society, as we will detail in the following.

### 3.4 | Increase the meaning and relevance of model results for practice and policy advice

In the context of unavoidable uncertainty, the meaning and relevance of modelling to operational entities like civil protection, the business sector and policy making is certainly more important than reducing predictive uncertainty to the maximum extent possible. Cooperation between science and practice, as between stakeholders and authorities, will remain highly relevant. Participatory scenario development may increase the understanding of scenarios and associated uncertainties, and thus also increase ownership and acceptability among potential users. From a policy perspective, addressing uncertainty might imply the need to focus more strongly on fit for purpose decision frameworks drawing on the precautionary principle, which would entail banning or at least reducing certain activities (Tosun, 2013). It also implies the need to focus on robust policies, which work well under different future contexts; as well as on stickiness of policies (Jordan & Matt, 2014), and on adaptability of strategies (Maier et al., 2016). Still, increasing meaning and relevance is not a panacea. Instead, there is a need to develop a reflective understanding of how scenarios fit into decision making in organizations and in society more generally, and to explore how the use of new scenarios might change current practice and governance (Fuller, 2017). This includes understanding the costs and benefits of new scenarios or scenario techniques but also the organizational and cultural transitions required to inform and strengthen adaptation and resilience.

### 3.5 | Fund more research that does not fit neatly within disciplinary boundaries

Understanding extremes and their interlinkages, drivers and impacts requires complex research approaches across disciplinary boundaries,

combining natural, engineering and social sciences. Still, this requirement needs to be reflected in water research funding and reward structures (e.g., opportunities for publication). Interdisciplinary and transdisciplinary water research—including co-production and reflection—requires funding not only from supporters of applied research but also by agencies funding basic research.

## 4 | CONCLUSION

Many of the current scenario studies on future water extremes do not seem to adequately address their emerging wickedness. Instead, they often focus on one of the extremes: floods or droughts or pollution, but not on the complexity of interlinkages between extremes. Also, very few studies seem to integrate the natural and the social science perspectives. Discussing these shortcomings during an expert workshop has led to five central recommendations that we summarize in this paper. These indicate how to develop scenarios that more adequately address the emerging wickedness of double or even triple water extremes. These scenarios then could help us to better anticipate and cope with future water extremes and increase resilience.

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### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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### REFERENCES

- Chambers, J. M., Wyborn, C., Ryan, M. E., Reid, R. S., Riechers, M., Serban, A., Bennett, N. J., Cvitanovic, C., Fernández-Giménez, M. E., Galvin, K. A., Goldstein, B. E., Klenk, N. L., Tengö, M., Brennan, R., Cockburn, J. J., Hill, R., Munera, C., Nel, J. L., Österblom, H., ...

- Pickering, T. (2021). Six modes of co-production for sustainability. *Nature Sustainability*, 4(11), 983–996. <https://doi.org/10.1038/s41893-021-00755-x>
- Doocy, S., Daniels, A., Murray, S., & Kirsch, T. D. (2013). The human impact of floods: A historical review of events 1980–2009 and systematic literature review. *PLoS Currents*, 5. <https://doi.org/10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a>
- Elsawah, S., Hamilton, S. H., Jakeman, A. J., Rothman, D., Schweizer, V., Trutnevyte, E., Carlsen, H., Drakes, C., Frame, B., Fu, B., Guivarch, C., Haasnoot, M., Kemp-Benedict, E., Kok, K., Kosow, H., Ryan, M., & van Delden, H. (2020). Scenario processes for socio-environmental systems analysis of futures: A review of recent efforts and a salient research agenda for supporting decision making. *Science of the Total Environment*, 729, 138393. <https://doi.org/10.1016/j.scitotenv.2020.138393>
- Fuller, T. (2017). Anxious relationships: The unmarked futures for post-normal scenarios in anticipatory systems. *Technological Forecasting and Social Change*, 124, 41–50. <https://doi.org/10.1016/j.techfore.2016.07.045>
- Grunwald, A. (2014). Modes of orientation provided by futures studies: Making sense of diversity and divergence. *European Journal of Futures Research*, 2(30). <https://doi.org/10.1007/s40309-013-0030-5>
- Guillaume, J. H. A., Helgeson, C., Elsawah, S., Jakeman, A. J., & Kumm, M. (2017). Toward best practice framing of uncertainty in scientific publications: A review of water resources research abstracts. *Water Resources Research*, 53(8), 6744–6762. <https://doi.org/10.1002/2017WR020609>
- Haasnoot, M., & Middelkoop, H. (2012). A history of futures: A review of scenario use in water policy studies in The Netherlands. *Environmental Science & Policy*, 19–20(6), 108–120. <https://doi.org/10.1016/j.envsci.2012.03.002>
- Hannah, D. M., Lynch, I., Mao, F., Miller, J. D., Young, S. L., & Krause, S. (2020). Water and sanitation for all in a pandemic. *Nature Sustainability*, 3(10), 773–775. <https://doi.org/10.1038/s41893-020-0593-7>
- Hrdinka, T., Novický, O., Hanslík, E., & Rieder, M. (2012). Possible impacts of floods and droughts on water quality. *Journal of Hydro-Environment Research*, 6(2), 145–150. <https://doi.org/10.1016/j.jher.2012.01.008>
- Jordan, A., & Matt, E. (2014). Designing policies that intentionally stick: Policy feedback in a changing climate. *Policy Sciences*, 47(3), 227–247. <https://doi.org/10.1007/s11077-014-9201-x>
- Kirschke, S., & Kosow, H. (2021). Designing policy mixes for emerging wicked problems. The case of pharmaceutical residues in freshwaters. *Journal of Environmental Policy and Planning*, 1–12. <https://doi.org/10.1080/1523908X.2021.1960808>
- Maier, H. R., Guillaume, J., van Delden, H., Riddell, G. A., Haasnoot, M., & Kwakkel, J. H. (2016). An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together? *Environmental Modelling & Software*, 81, 154–164. <https://doi.org/10.1016/j.envsoft.2016.03.014>
- Tosun, J. (2013). How the EU handles uncertain risks: Understanding the role of the precautionary principle. *Journal of European Public Policy*, 20(10), 1517–1528. <https://doi.org/10.1080/13501763.2013.834549>
- Tosun, J., & Howlett, M. (2021). Managing slow onset events related to climate change: The role of public bureaucracy. *Current Opinion in Environmental Sustainability*, 50, 43–53. <https://doi.org/10.1016/j.cosust.2021.02.003>

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